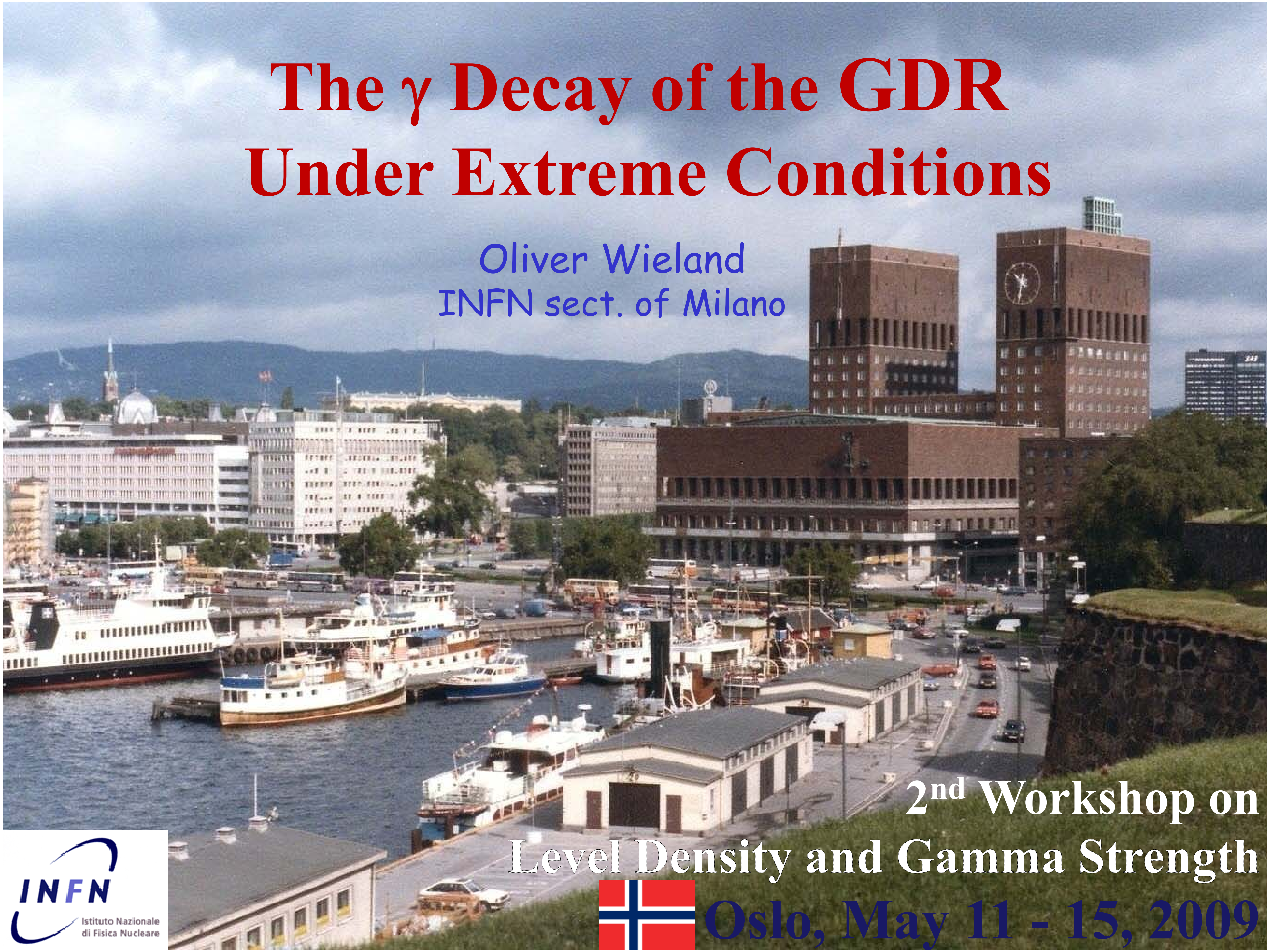
# The $\gamma$ Decay of the GDR Under Extreme Conditions

Oliver Wieland
INFN sect. of Milano



2nd Workshop on
Level Density and Gamma Strength
Oslo, May 11 - 15, 2009

INFN Istituto Nazionale di Fisica Nucleare

# OUTLINE :

## Measurement with *exotic* beams

RISING

- 1. The Pygmy Dipole Resonance (PDR) in neutron rich nuclei ($^{68}$Ni)

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## Measurement with *stable* beams

G.AR.F.I.E.L.D.
HECTOR

- 1. Measurement of the Isospin mixing in the N=Z nucleus $^{80}$Zr at T≈2MeV with use of Giant Dipole Resonance (GDR)
- (2. GDR in Highly Excited $^{132}$Ce Nuclei)

INFN Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Legnaro

Study of $LaBr_3$:Ce Scintillators
for application in High energy gamma ray spectroscopy

Milano
INFN Istituto Nazionale di Fisica Nucleare

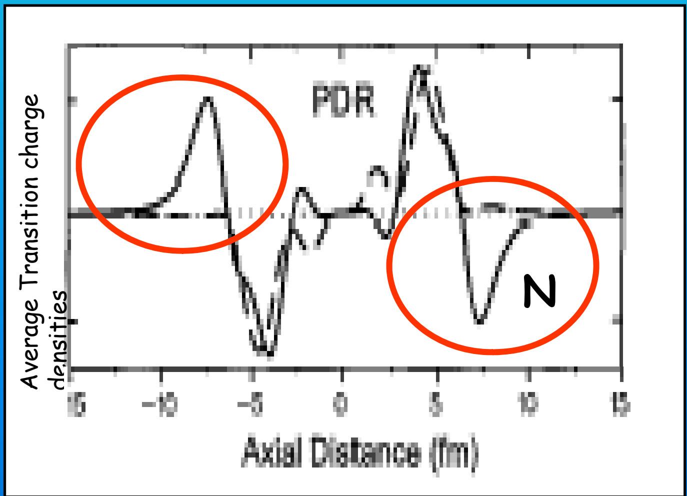
# 2. Measurements with *exotic* beams

## 3. The Pygmy Dipole Resonance (PDR) in neutron rich nuclei ($^{68}$Ni)

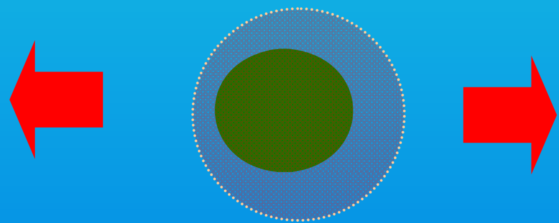
RISING

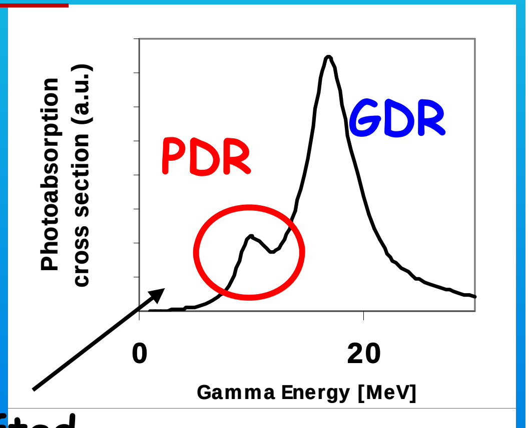
## Pygmy Dipole Resonance

**Simple picture**: More or less Collective (coherently) oscillation of (loosely bound) neutron skin against the core




Richter NPA 731(2004)59





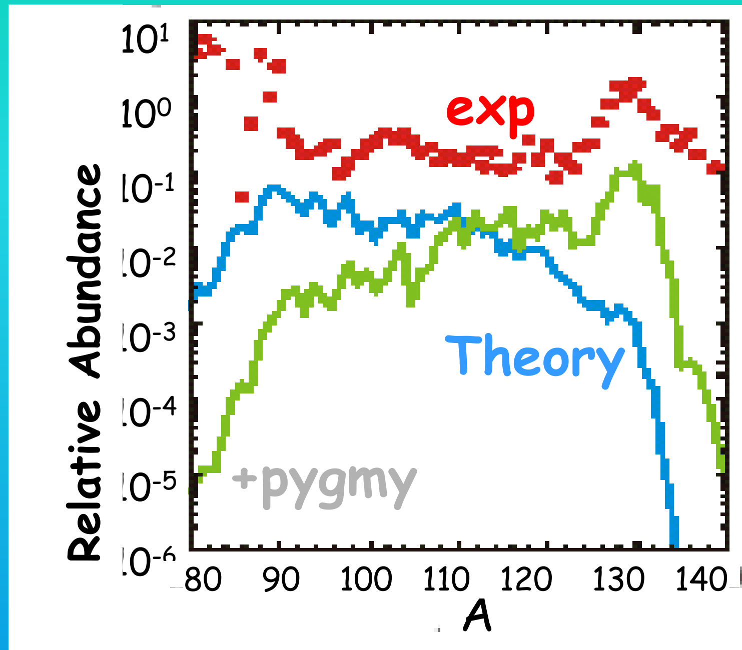

E1 strength **shifted** towards low energy (centroid energy depends on the thickness of n-skin)

# Why ?...(very brief)

**Pygmy Resonance may have an very important impact on the r-process nucleosynthesis**

Giant resonances are of paramount importance for nuclear astrophysics. Often, relevant reaction rates under astrophysical conditions are dominated by giant-resonance contributions, frequently in unstable nuclei. For instance, neutron-rich nuclei with loosely bound valence neutrons may exhibit very strong (γ,n) strength components near particle threshold and thus, in turn, enhanced neutron-capture rates. Re-

Nupecc long range plan 2004

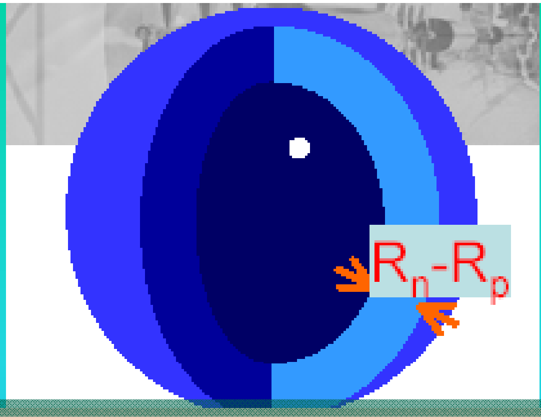



S.Goriely, Phys. Lett. B436 10 (1998)
S.Goriely and E. Khan, Nucl. Phys. A706 (2002) 217

**AND** ▸ how **collective properties** change with **neutron** number

**AND...**

# PYGMY resonance and Neutron Skin radius



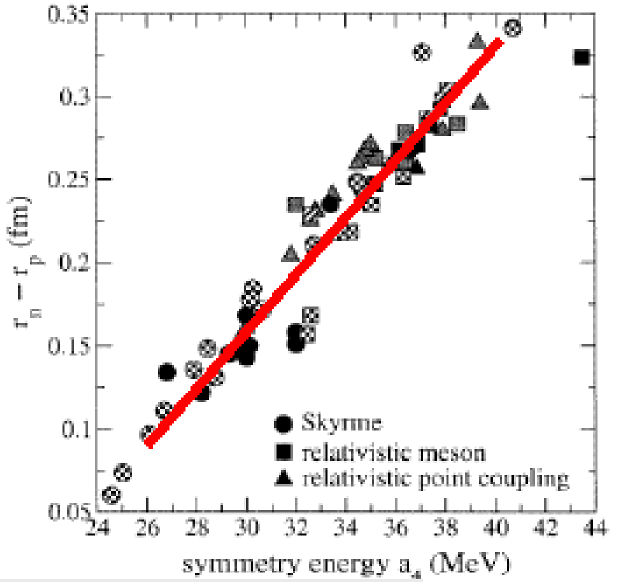

Excess neutrons forming the **skin** gives rise to pygmy dipole transitions at excitation energies below the **GDR**.

**Relation between symmetry energy and Radius of neutron Skin** (Furnstahl relation)

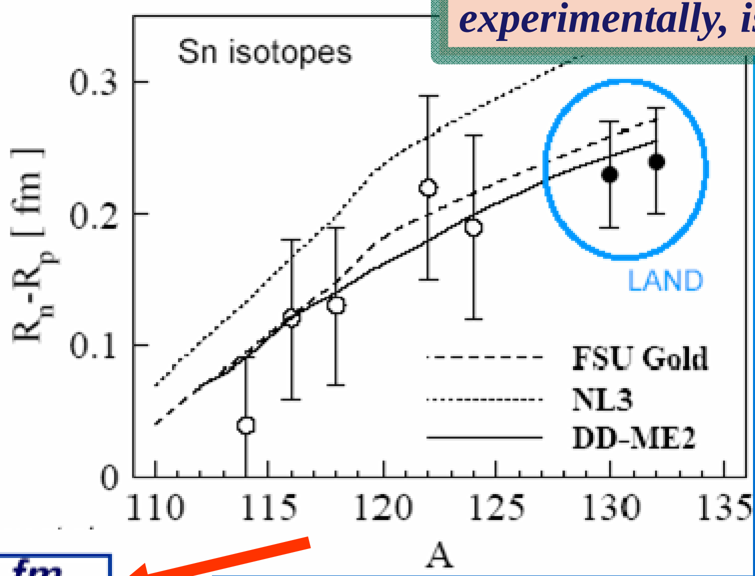
… AND Pygmy resonance (Energy, EWSR), since related to skin

**Precise knowledge of neutron-skin thickness could constrain the density dependence of S(ρ)**

**Pygmy-Strength (since related to skin) should do the same job, *but, experimentally, is accessed much easier !***




(Furnstahl relation NPA706 (02))

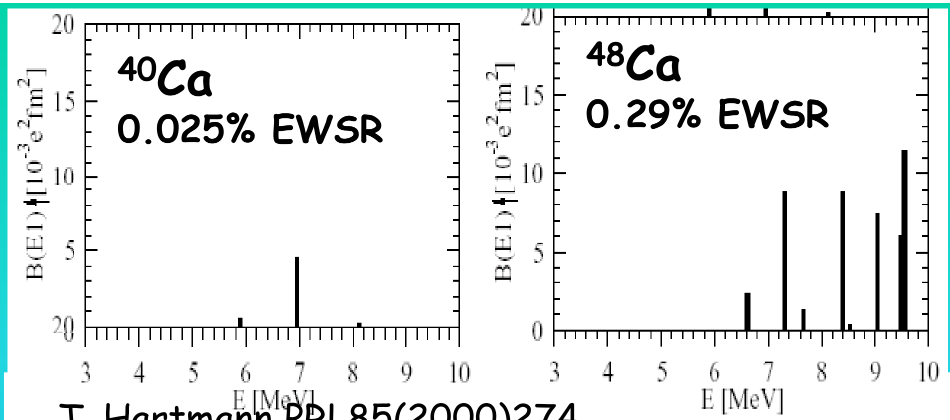



$R_n - R_p = 0.18 \pm 0.035$ fm

Extrapolation for Pb

# How to excite this mode??

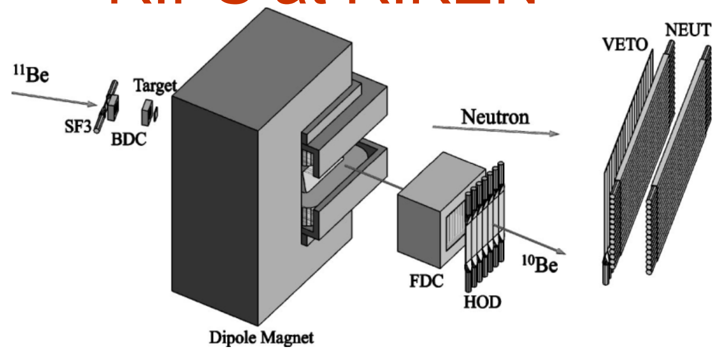
**Stable nuclei** ⇒
photon
scattering,Photoabsorption
 $(\gamma,\gamma')$,$(\gamma,n)$...



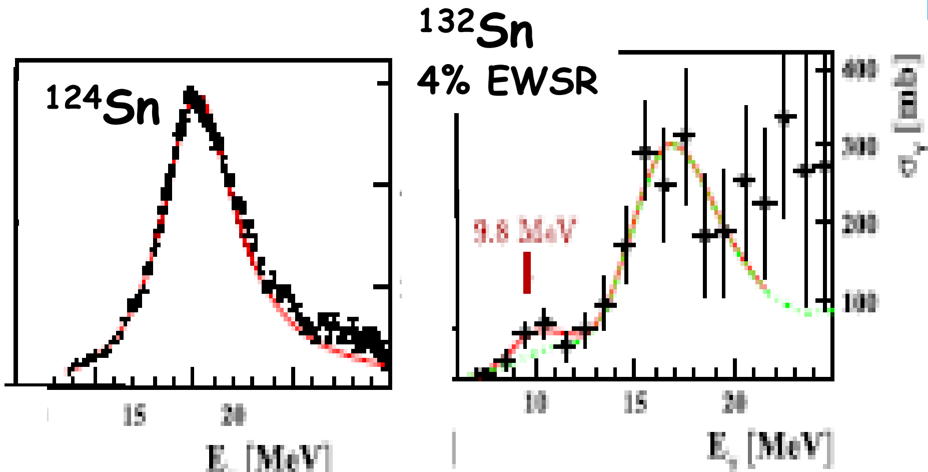
T. Hartmann PRL85(2000)274

**Exotic nuclei**⇒
Virtual photon breakup
or Virtual photon scattering

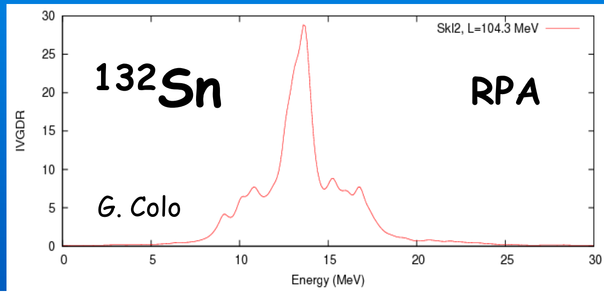
RIPS at RIKEN




Soft E1 Excitation with
Coulomb Breakup of $^{11}$Be,..
T.Nakamura *et al.*, PLB 331,296(1994)
N.Fukuda et al., PRC70, 054606 (2004)



Adrich et al. PRL 95(2005)132501 LAND at GSI

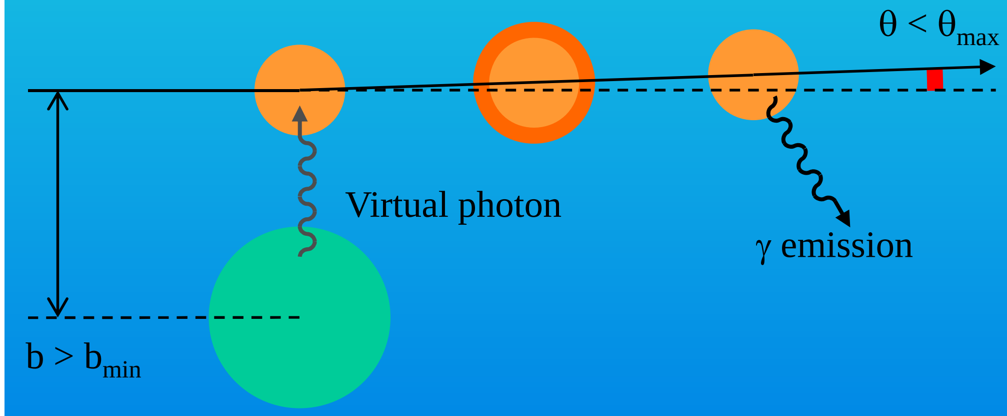


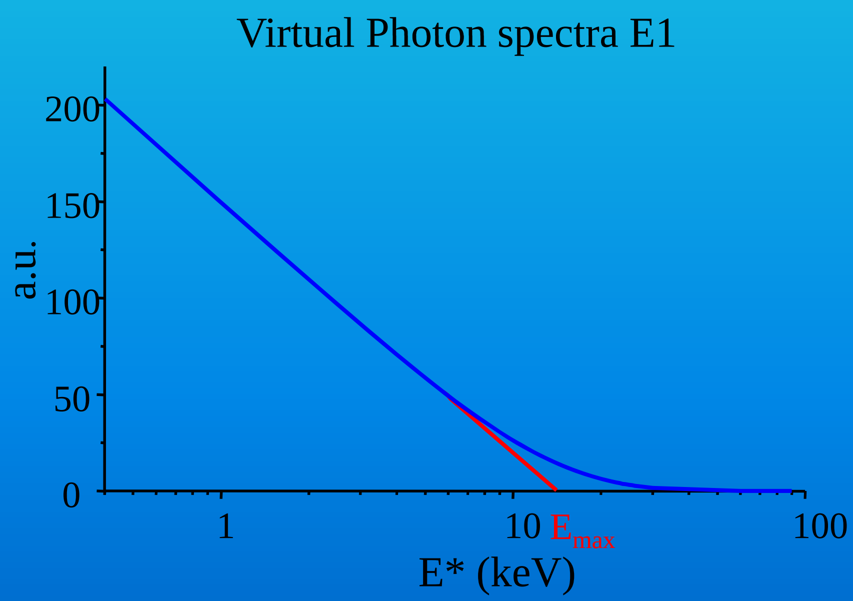
# Virtual photon scattering technique (1)

- Peripheral heavy-ion collision on a high Z target at relativistic energies
- Virtual photon excitation and decay

$$^{197}\mathrm{Au}(^{68}\mathrm{Ni},{}^{68}\mathrm{Ni}^{*}+\gamma)^{197}\mathrm{Au}$$

Relativistic Coulomb excitation (v/c ~ 0.8%)




$$\frac{d\sigma_C}{dE^*} = \sum_{\pi\lambda} \frac{1}{E^*} N_{\gamma}^{\pi\lambda}(E^*) \cdot \sigma_{\gamma}^{\pi\lambda}(E^*)$$

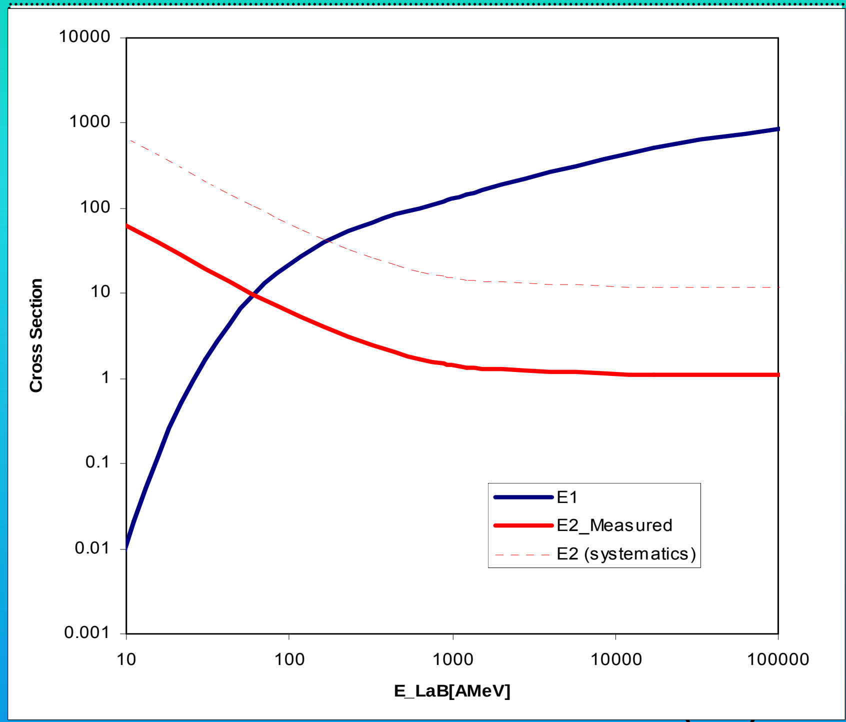
$$E_{max} = \frac{\beta\gamma}{b_{min}} \hbar c$$

Virtual photon scattering technique (2)

•High **selectivity** for dipole excitation !!

**GDR + PYGMY Excitation**

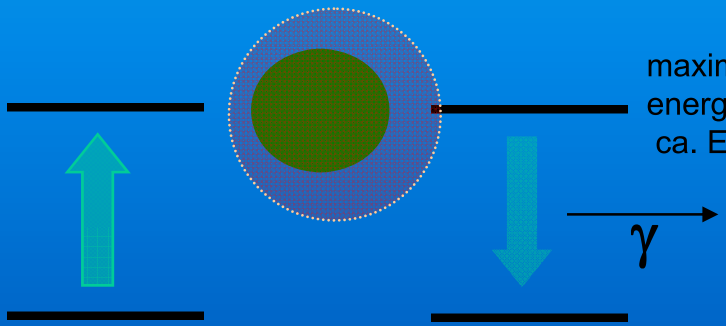
**600 MeV/u $^{68}$Ni + $^{197}$Au (April 2005)**
**400 MeV/u $^{68}$Ni + $^{197}$Au (May 2004)**




$$\frac{\sigma(GDR)}{\sigma(GQR)} \approx 20$$

Virtual photon excitation and decay of **GDR - PYGMY**

→At large energies the cross section for the Coulomb excitation of the GR **overcomes** the nuclear geometrical cross section!




maximum excitation energy (adiabatic cut off) ca. E*max=18.5 MeV

**Coulex** g.s.

**GDR Ground state decay branching ratio ~ 2% measured on $^{208}$Pb**

[Beene et al PRC 41(1990)920]

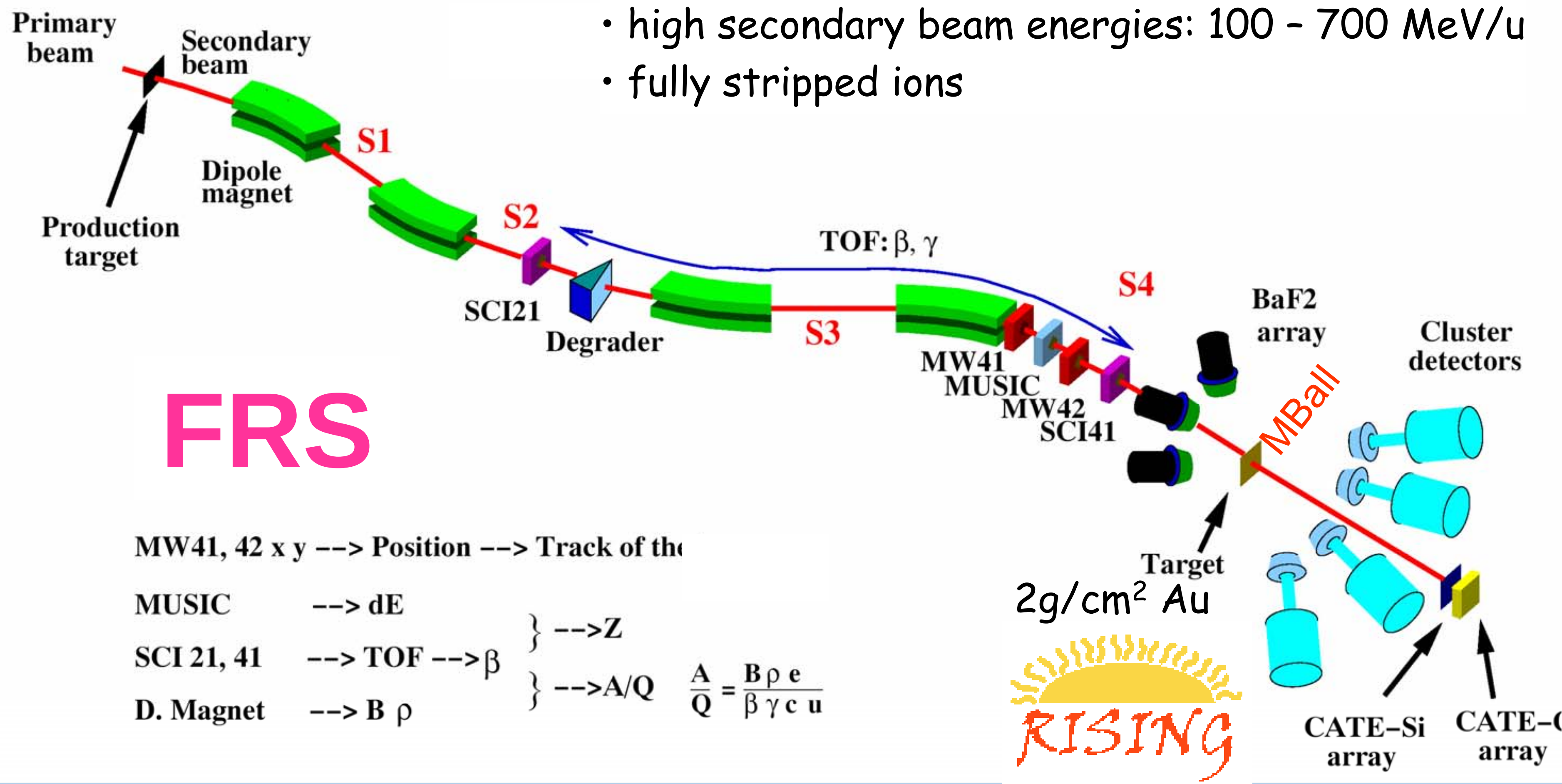
# High resolution γ-spectroscopy at the FRS

$^{68}Ni$ beam produced by fragmentation of $^{86}Kr$ @ 900 MeV/u on thick Be target (4g/cm$^2$):

- $10^{10}$ ppspill $^{86}Kr$
- Spill length 6s, period 10 s

FRS provides secondary radioactive ion beams:

- fragmentation and fission of primary beams
- high secondary beam energies: 100 – 700 MeV/u
- fully stripped ions



# Coulomb excitation of $^{68}$Ni @ 600 AMeV

## FRS+RISING ARRAY

Euroball 15 Clusters

Located at 16.5°, 33°, 36°
Energetic threshold ~ 100 keV

Hector 8 $BaF_2$

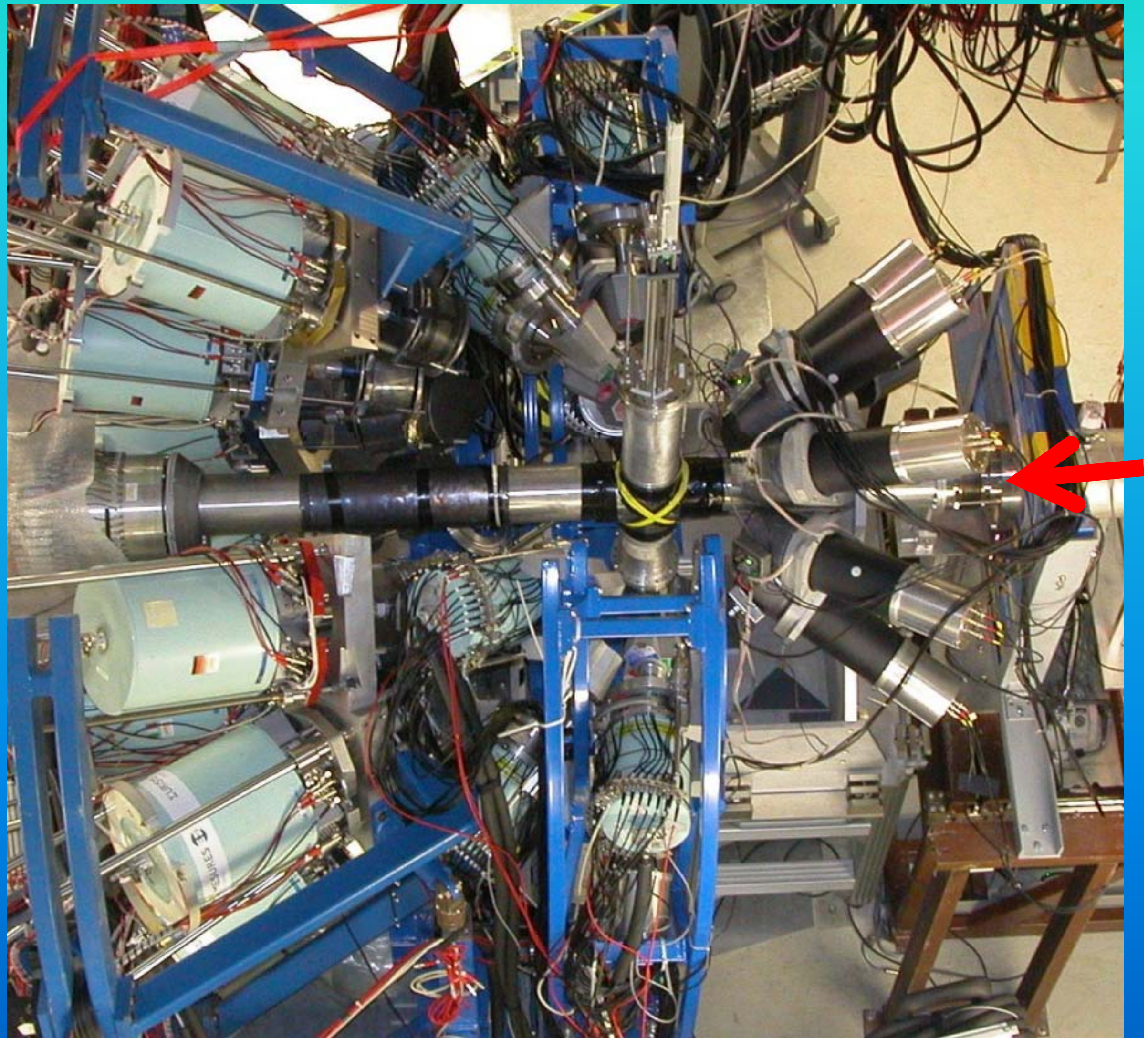
Located at 142° and 88°
Energetic threshold ~ 2 MeV

Miniball 7 HPGe segmented detectors

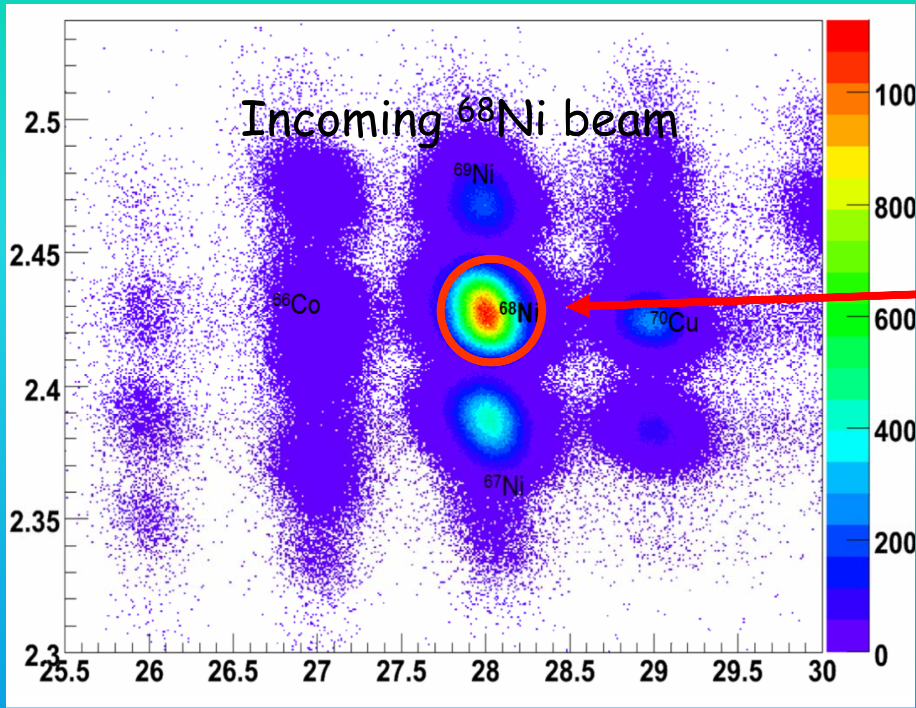
Located at 46°, 60°, 80°, 90°
Energetic threshold ~ 100 keV

Beam identification and tracking detectors

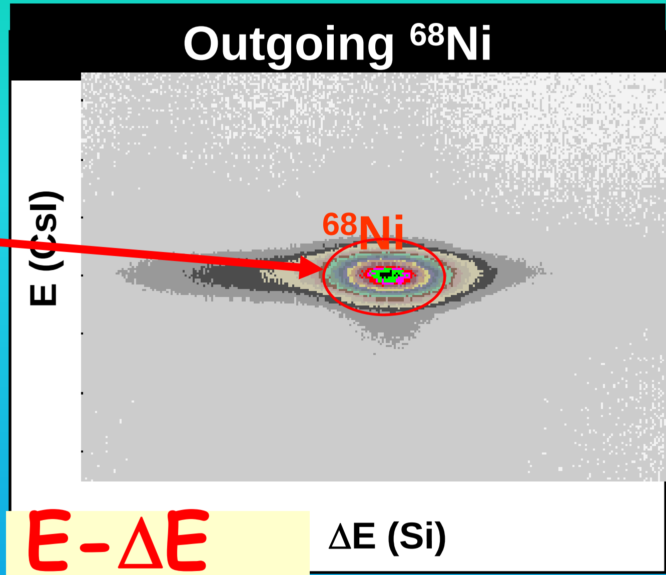
**Before** and **after** the target



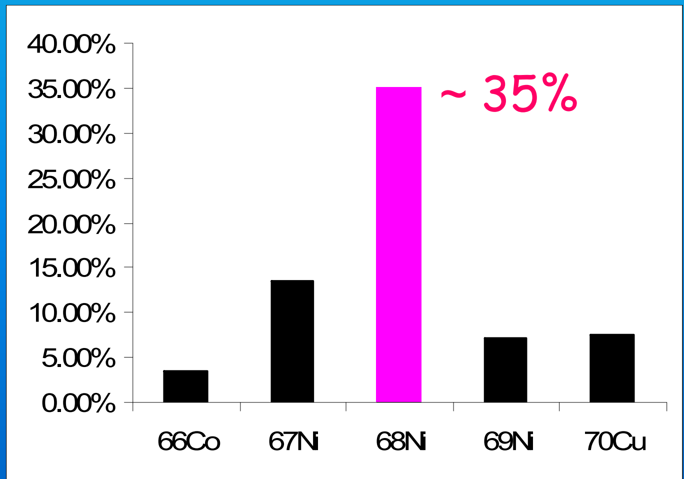
# Coulomb excitation of $^{68}$Ni @ 600 AMeV




GATE




E-ΔE telescopes

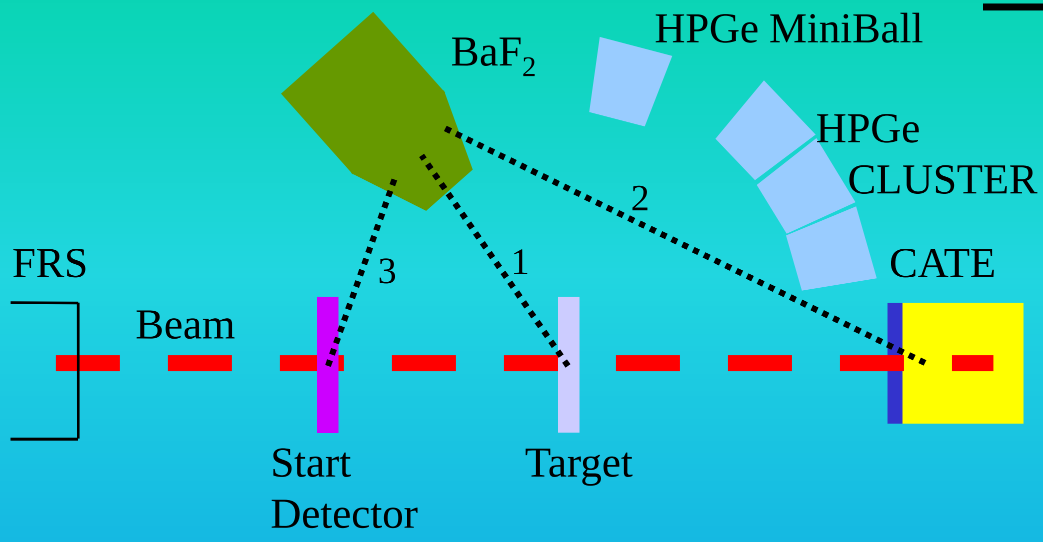


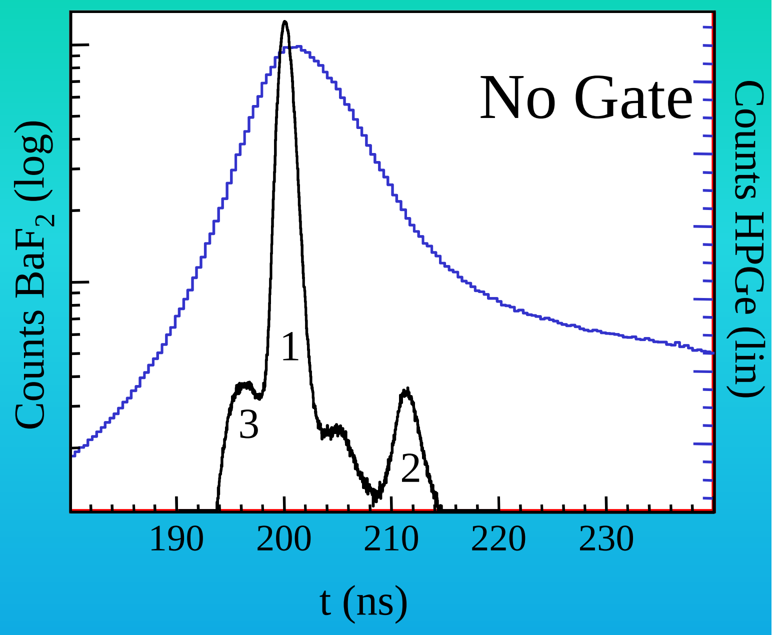

~ 6 Days of effective beam time
~ 400 GB of data recorded

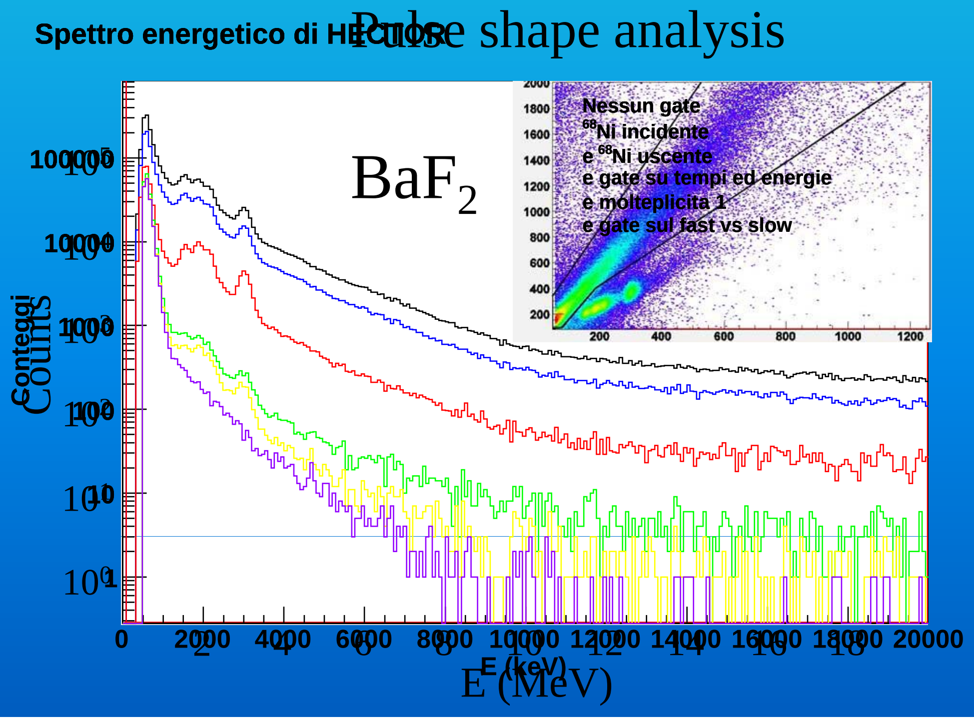
~ $1 \cdot 10^8$ ' good $^{68}$Ni events '

Incoming+Outgoing $^{68}$Ni

# Technical Details

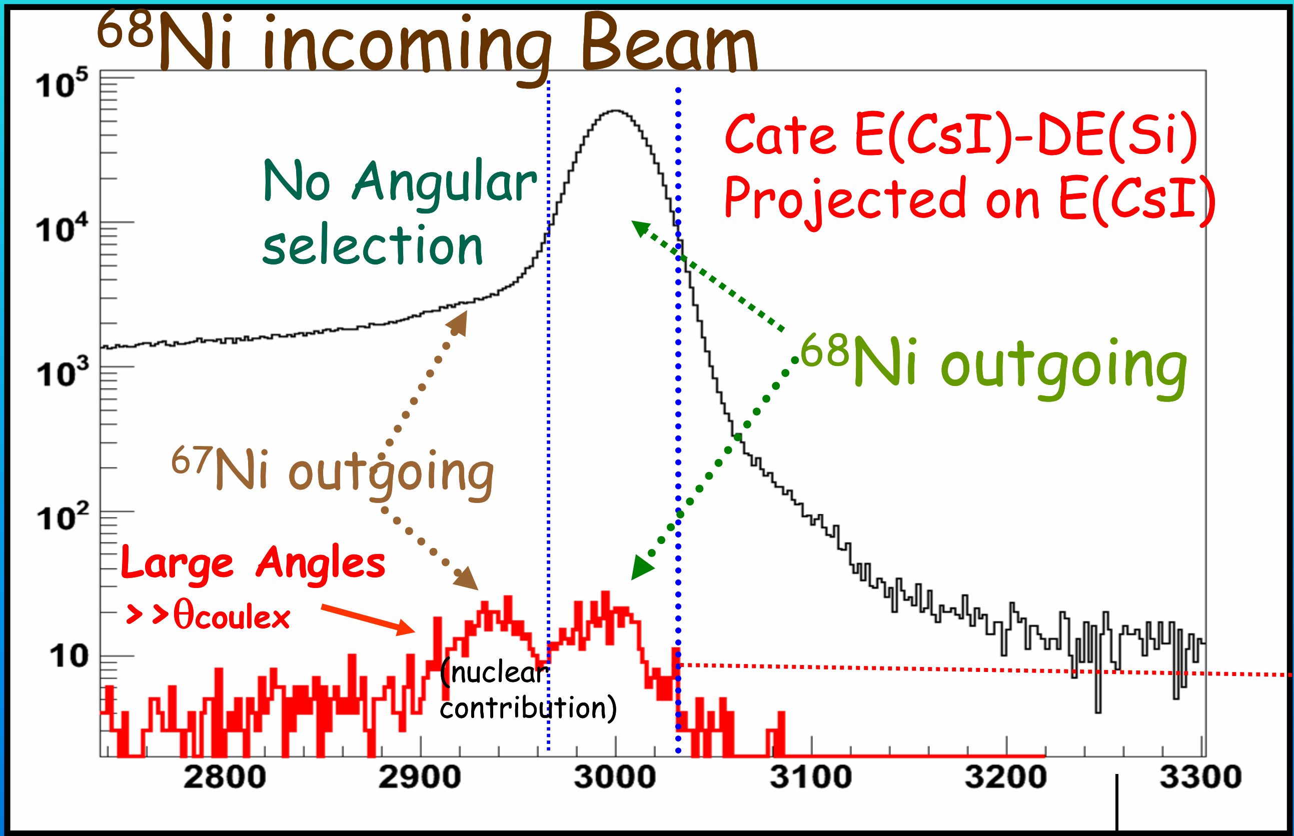



| | Condizioni | HPGe | BaF$_2$ |
|---|---|---|---|
| | No gate | 100 % | 100 % |
| | $^{68}$Ni in | 62 % | 60 % |
| | + $^{68}$Ni out | 15 % | 18 % |
| | + prompt | 8.6 % | 7.4 % |
| | + $M_\gamma$ = 1 | 7.8 % | 6.3 % |
| | + fast vs slow PSA | | 6.0 % |

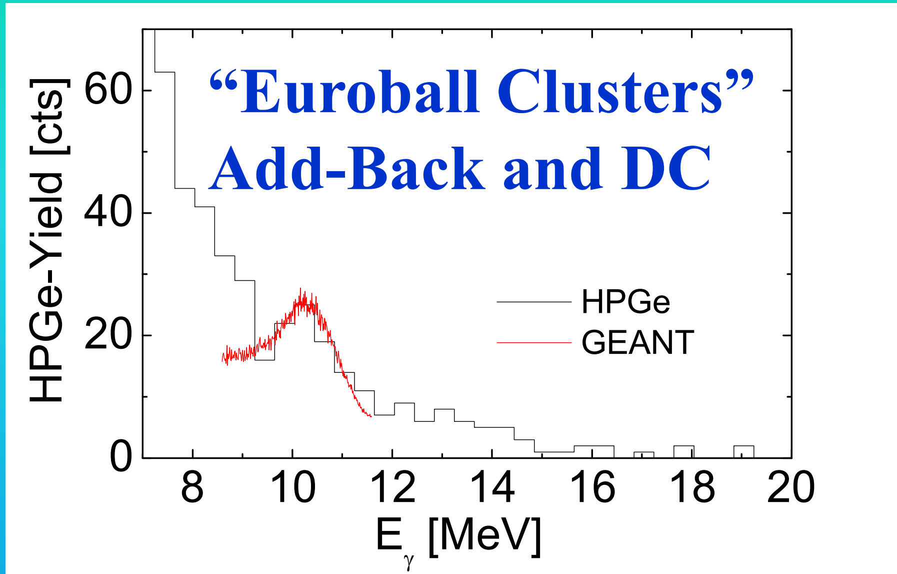
# Spectrum of the ejectile measured in the zero degree calorimeter (CATE)

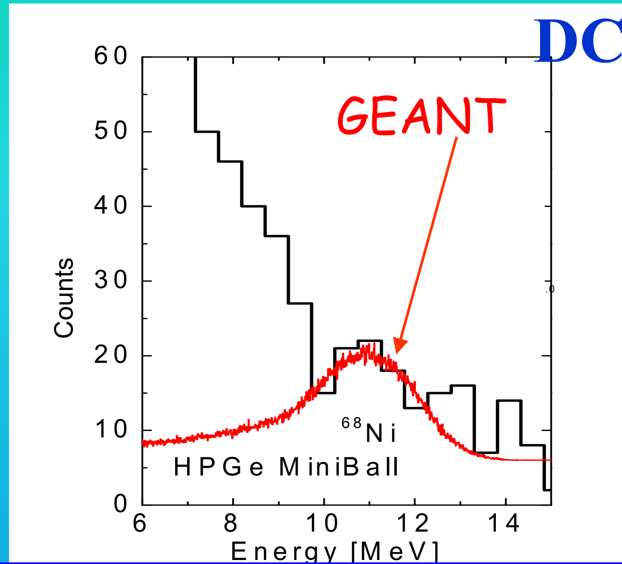



Good selection of $^{68}$Ni after the interaction with Au target

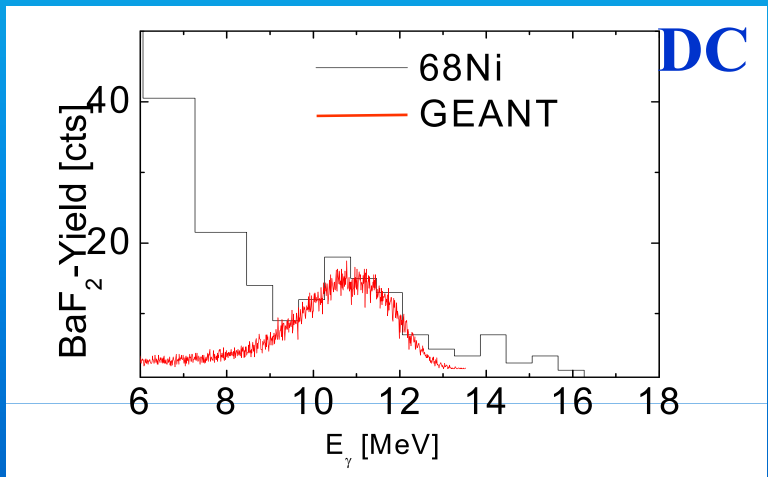
At b<<b_min contributions from Coulomb and Nuclear interaction

# RESULTS Coulomb excitation : $^{197}$Au($^{68}$Ni@600AMeV,$^{68}$Ni*)$^{197}$Au




**Forward : EUROBALL HPGe** **Center:MINIBALL**

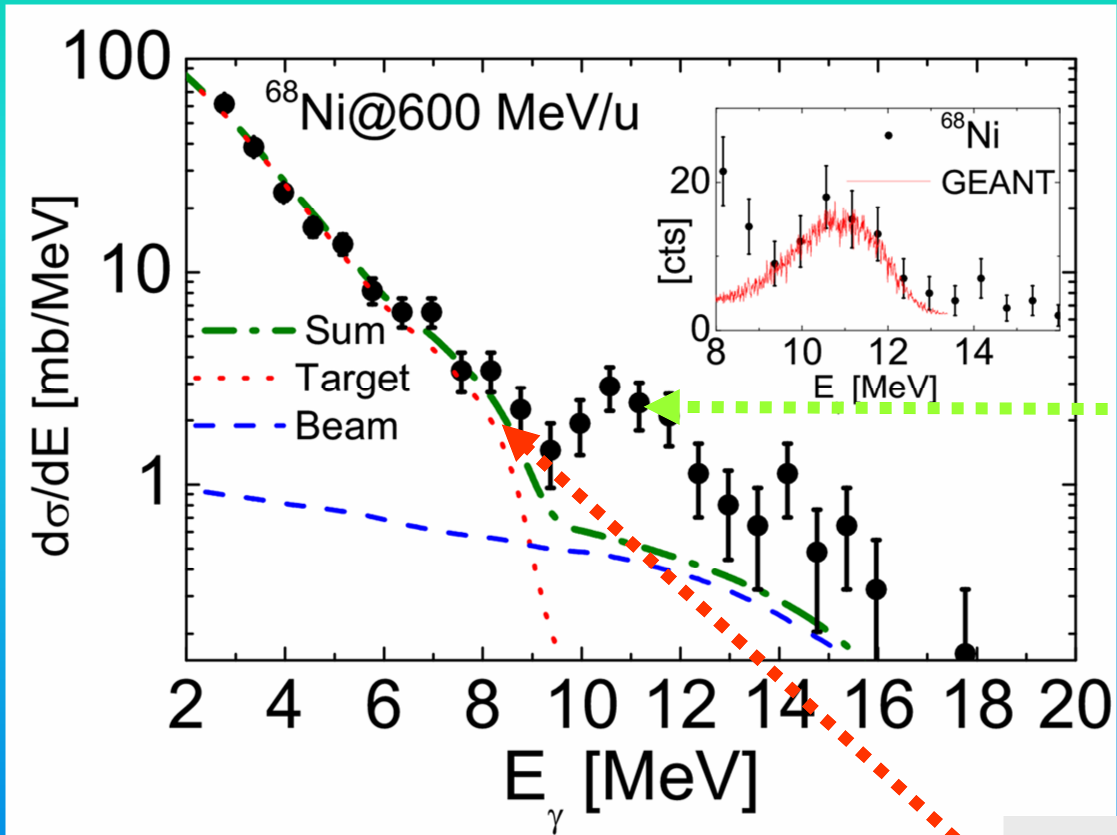



**Backward HECTOR $BaF_2$**

**Structure @ 11 MeV in *all* detectors**

following lorentz boost and E1 angular distribution

# $\gamma$-rays spectrum of $BaF_2$ detectors




an excess yield due to beam emission !!

Conditions:

- $^{68}$Ni-incoming-selection
- $^{68}$Ni-outgoing-selection
- TOF-in prompt
- Outgoing angle check
- Doppler correction
- m$\gamma$=1

Statistical emission of $\gamma$-rays from :

target nuclei ($^{197}$Au)
beam nuclei ($^{68}$Ni)

folded with Response Function including Doppler correction!

# Data Analysis

**Coulomb excitation Yield is product of 3 terms:**

**Virtual photo number, photoabsorption cross section, Branching**

$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

[… Beene, Bortignon, Bertulani …]

**Calculate the ground state γ-ray decay from a GR state following a Coulomb excitation**

**! Coulomb excitation probability is directly proportional to the Photonuclear cross section**

[Eisenberg,Greiner, Bertulani,Alder,Winther,…]

$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma).$$

The functions $n_{\pi\lambda}(\varepsilon)$ are called the *virtual photon numbers*, and are given by

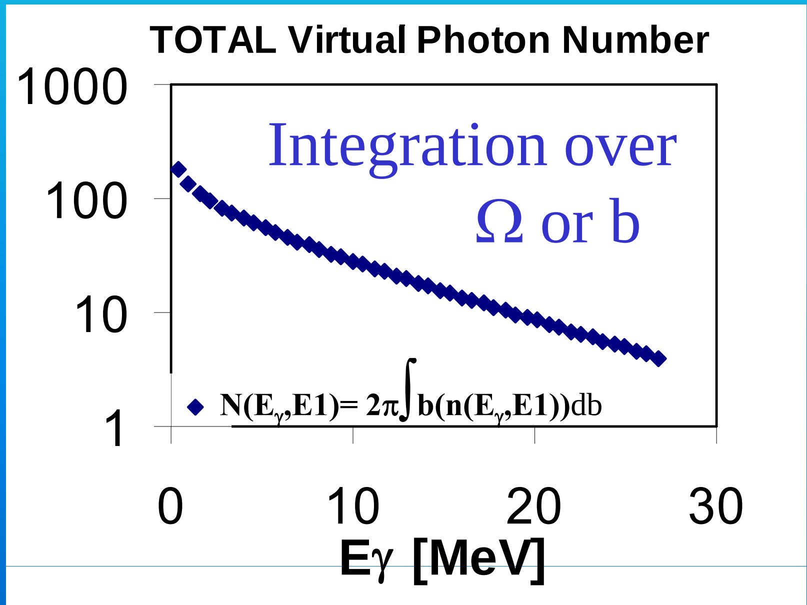
$$n_{E1}(b,\varepsilon) = \frac{Z_1^2\alpha}{\pi^2}\frac{\xi^2}{b^2}\left(\frac{c}{v}\right)^2\left\{K_1^2 + \frac{1}{\gamma^2}K_0^2\right\}$$

*= number of equivalent photons*

*Does **NOT** depend on the nuclear structure !*

**Equivalent(virtual)-photon method**

*Flux of virtual photons per unit area impinging on collision partners.*



# Gamma decay -
# Branching ratio and level density

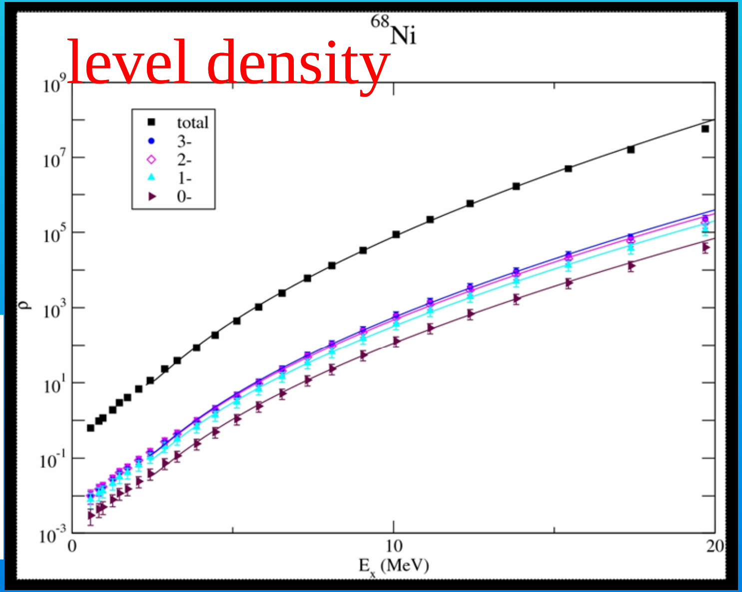
$$\frac{d^2\sigma_{C\gamma}}{d\Omega dE_\gamma}(E_\gamma) = \frac{1}{E_\gamma}\frac{dn_\gamma}{d\Omega}(E_\gamma)\,\sigma_\gamma(E_\gamma)\,R_\gamma(E_\gamma),$$

## Branching Ratio for γ

**Double-contribution model*,**
direct GR decay + the compound states :

$$R_\gamma(E_\gamma, \rho_{LD}) = \frac{\Gamma_0^{GR}}{\Gamma^{GR}} + \frac{\Gamma^{GR\downarrow}}{\Gamma^{GR}} C \frac{<\Gamma_0^c>}{<\Gamma^c>}.$$

*[Beene, et al PLB (1985) and ref therein]




C.N. Gilbreth and Y. Alhassid, private communication
Shell model Monte Carlo (SMMC)
Y. Alhassid et al. PRL 99, 162504 (2007)

## (GDR-PDR) Coulomb excitation of $^{26}$Ne or $^{68}$Ni at relativistic energies

The extraction of the B(E1) strength requires the estimation of the direct and compound γ-decay of the dipole state to the ground state

[Beene, et al PLB (1985)]

$$R_{decay}(E1) = \left[ \frac{\Gamma^{\uparrow}_{\gamma 0}}{\Gamma} + C \frac{\Gamma^{\downarrow}}{\Gamma} \frac{\langle \Gamma^{CN}_{\gamma 0} \rangle}{\langle \Gamma^{CN} \rangle} \right]$$

J.Beene et al PRC 41(1990)920

The compound term depends on the <u>ratio</u> between the <u>gamma and total decay width</u>

$$\langle \Gamma^{CN}_{\gamma 0} \rangle = \frac{2}{\pi} \frac{\Gamma^{\uparrow}_{\gamma 0}}{\Gamma^{\downarrow}} \frac{1}{\rho}$$

J.Beene et al PLB 164(1985)1

The gamma decay width depends on
The value of the **<u>level density</u>** <u>at the resonance energy</u>

Direct $\Gamma^{\uparrow}_{\gamma_0} = \frac{1}{3\pi^2(\hbar c)^2} E^2 \sigma_{int}$

$\sigma_{int}$ = photo-absorption cross-section

Spreading width

$\frac{\Gamma^{\downarrow}}{\Gamma} \simeq 1$ Heavier nuclei

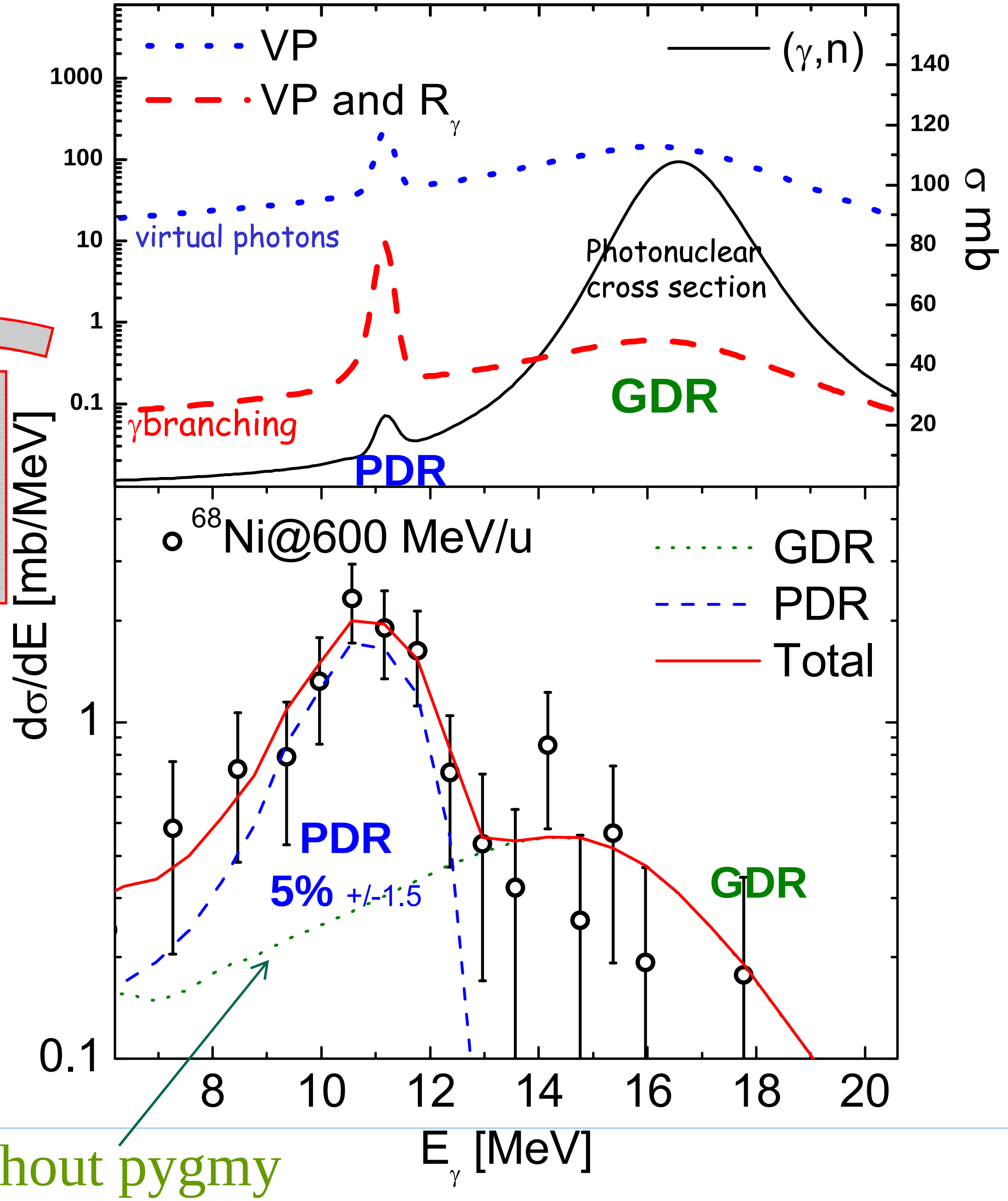
$\frac{\Gamma^{\downarrow}}{\Gamma} < 1$ Lighter nuclei

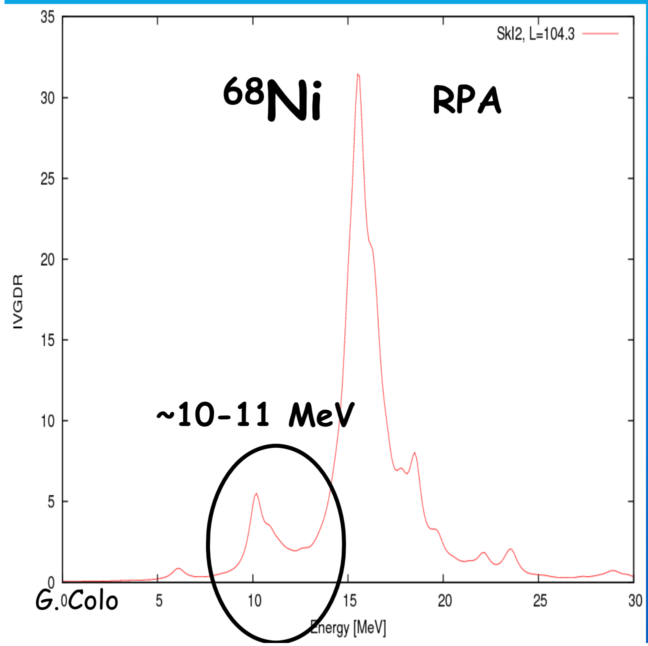
**Relativistic Coulomb excitation probability is directly proportional** [Eisenberg,Greiner, Bertulani, Baur, Alder,Winther, Weizsaecker, Williams…] **to the Photonuclear cross section**

$$\frac{d\sigma_{C\gamma}}{dE_\gamma} = RF\left\{\frac{1}{E_\gamma} N_\gamma(E_\gamma)\cdot\sigma_\gamma(E_\gamma)\cdot R_\gamma(E_\gamma)\right\}$$

ResponseFunction

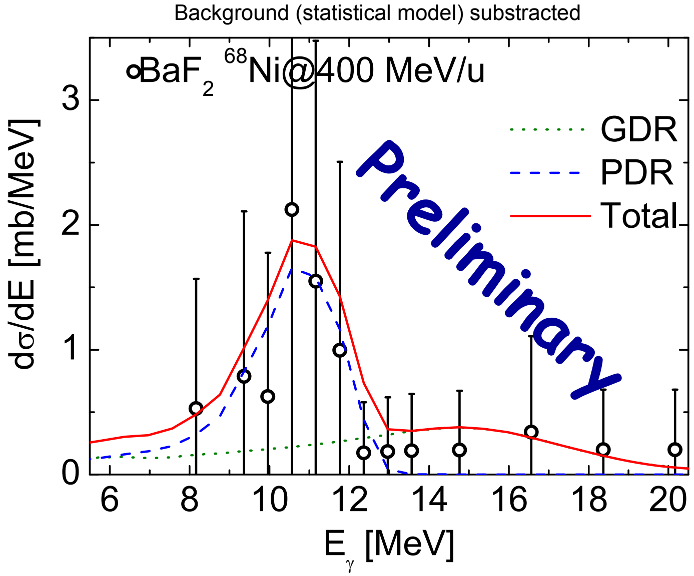
Folded with the **detector response function**



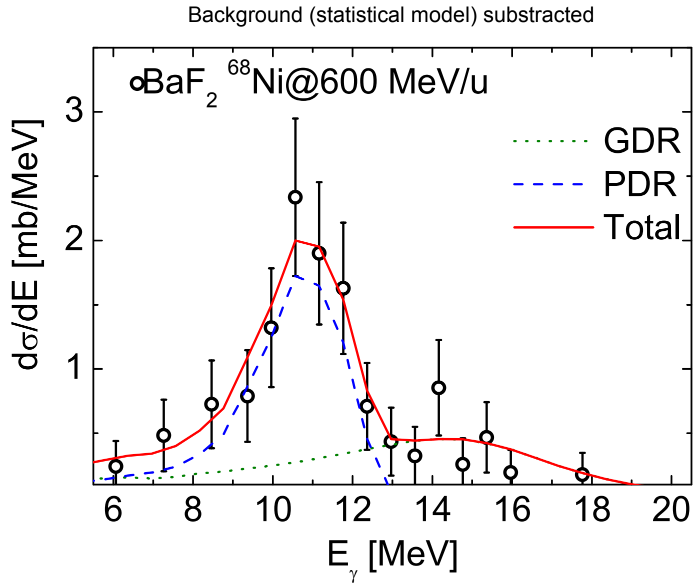



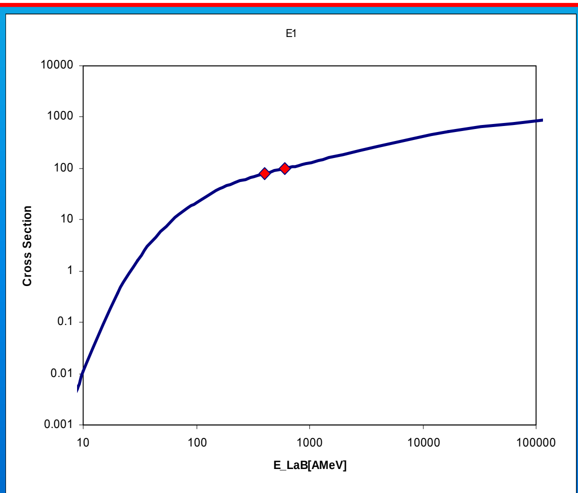

O.Wieland et al. PRL 102, 092502 (2009)

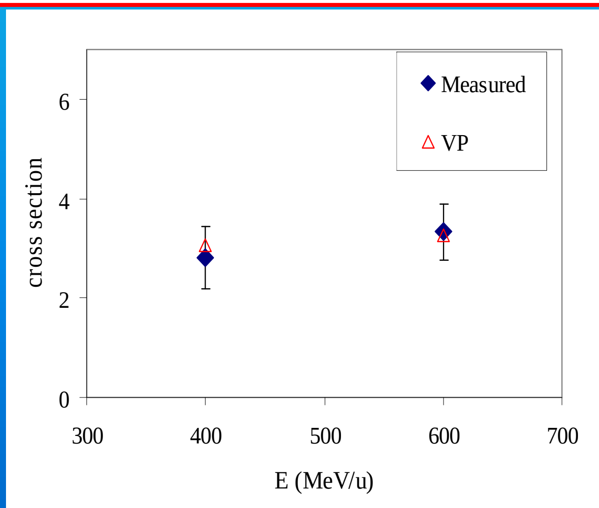
# IMPORTANT
# Cross CHECK !




$BaF_2$



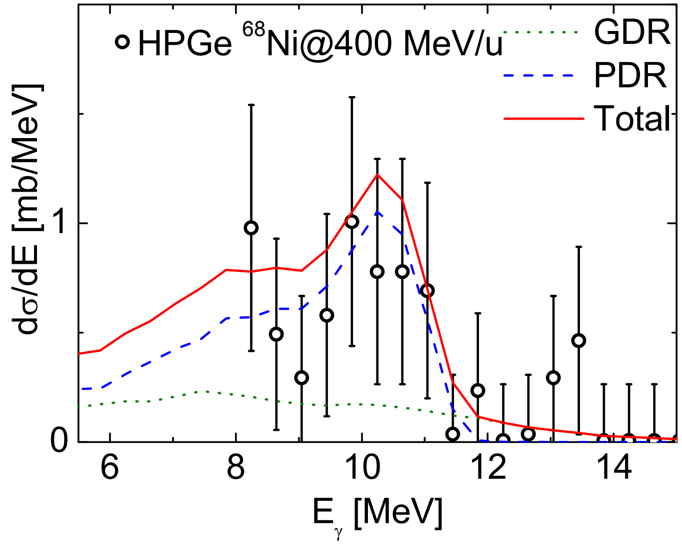



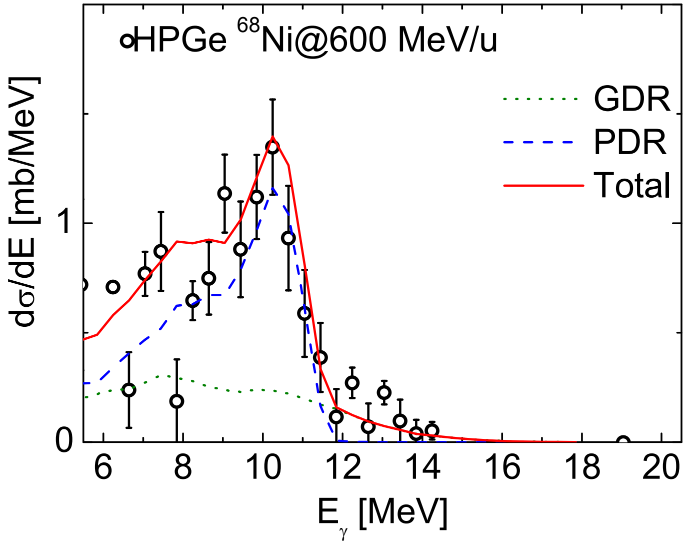

Integrated over whole GDR
Increase is +25%

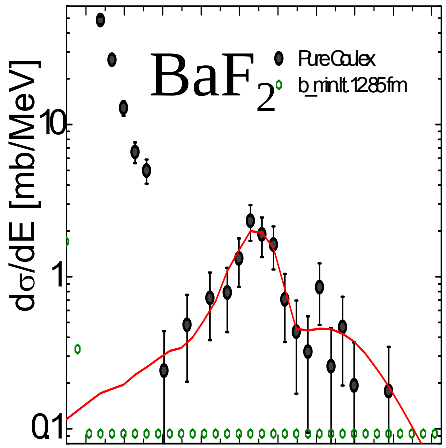
Integrated over PDR
(with detector response function)
Increase is +7%

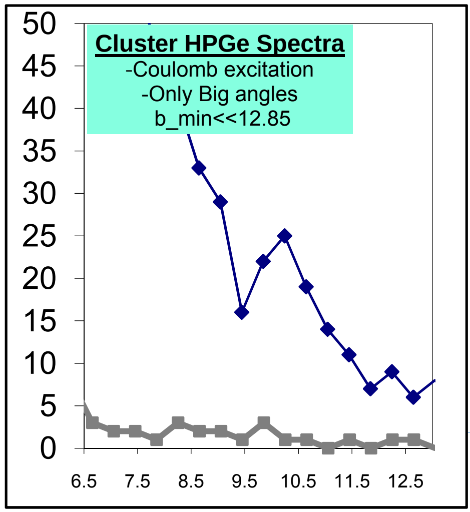
Euroball Clusters of HPGe

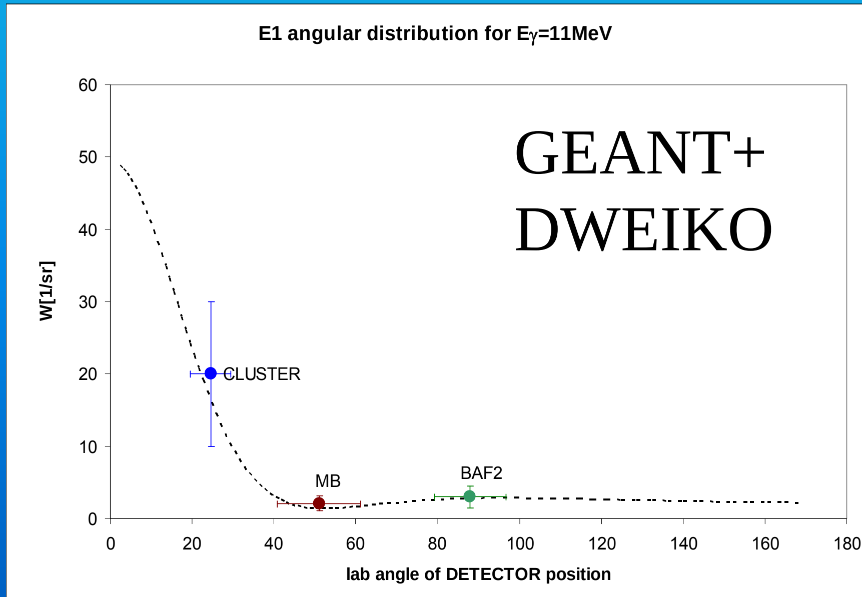
IMPORTANT Cross CHECK !



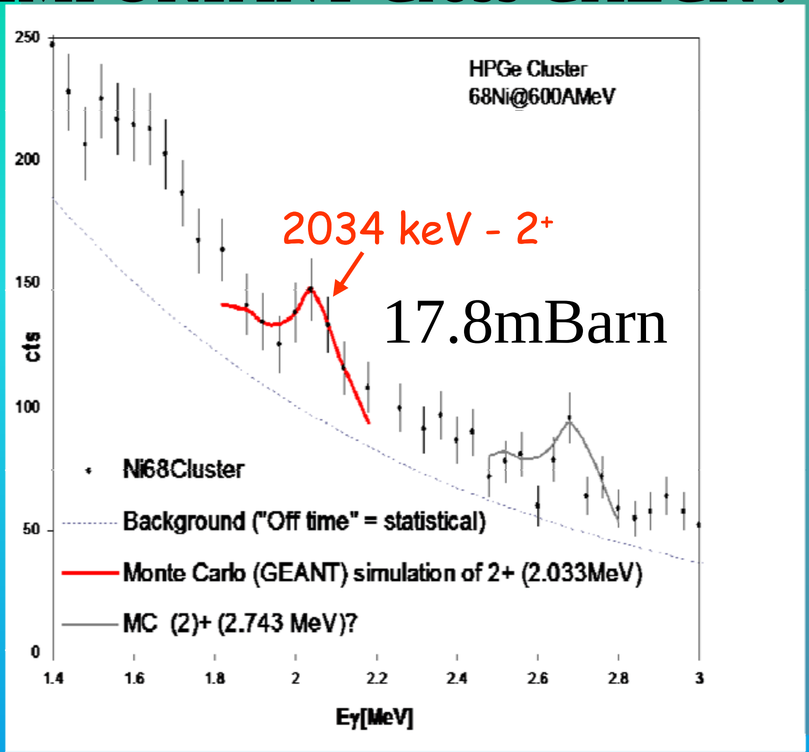



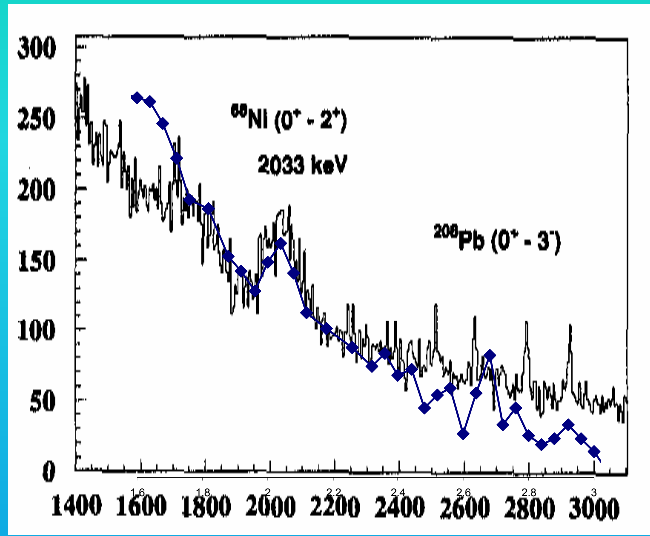



# IMPORTANT Cross CHECK !




Euroball Clusters of HPGe

## $B(E2)$ of $^{68}$Ni

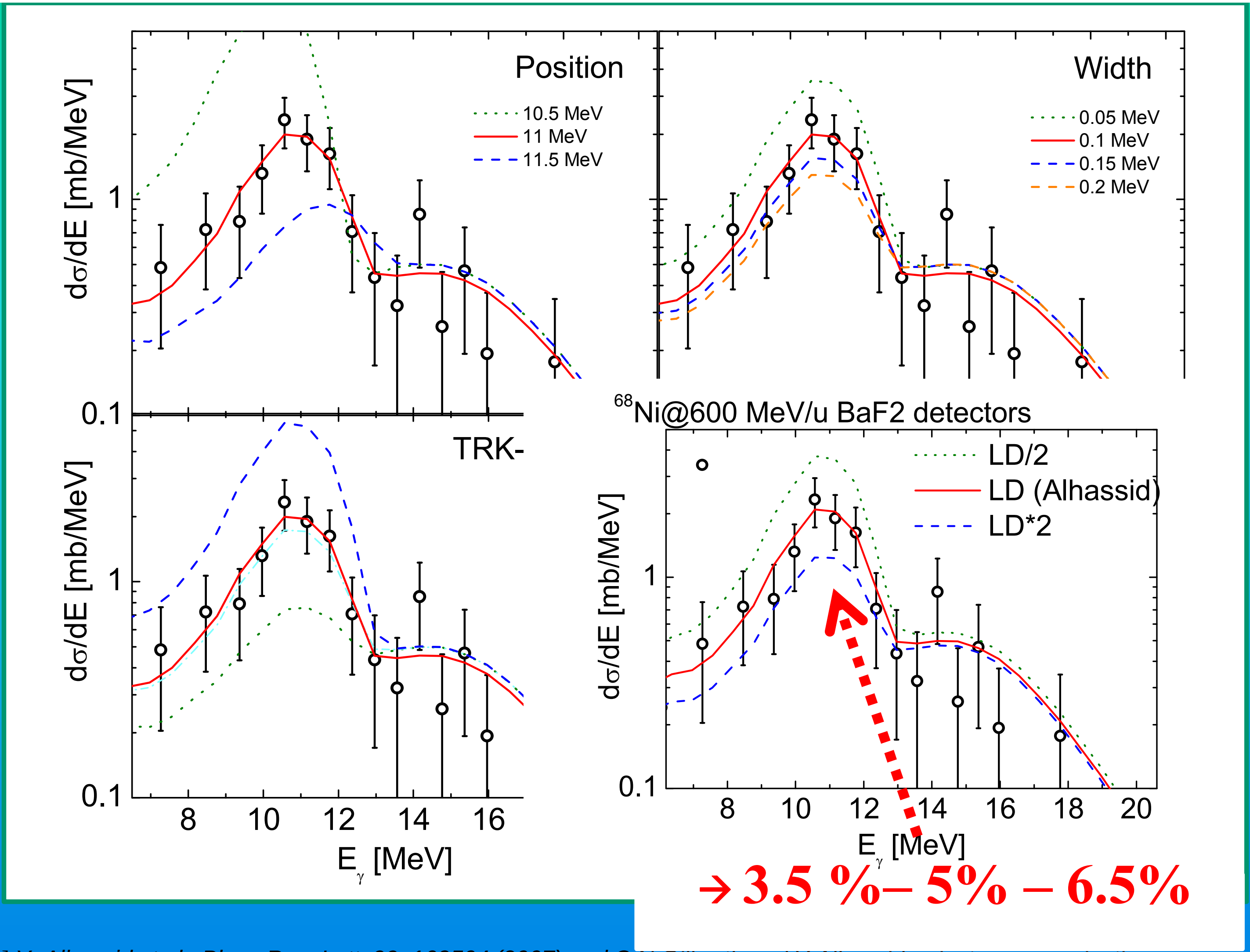



O. Sorlin et al., Phys. Rev. Lett. 88, 092501 (2002).

$$\sigma_{E2}^{(app)} = \frac{8\pi^2}{75}\frac{Z_T^2\alpha}{(\hbar c)^3}E_x^3 B(E2)\left(\frac{c}{v}\right)^4\left[\frac{2}{\gamma^2}K_1^2 + \xi\left(1+\frac{1}{\gamma^2}\right)^2 K_0K_1 - \frac{v^4\xi^2}{2c^4}\left(K_1^2 - K_0^2\right)\right]$$

→ With B(E2)=255e^2fm^4 → 18mBarn

**$b_{min}$=1.34*(ap^(1/3)+at^(1/3))-(ap^(-1/3)+at^(-1/3))=12.85fm**

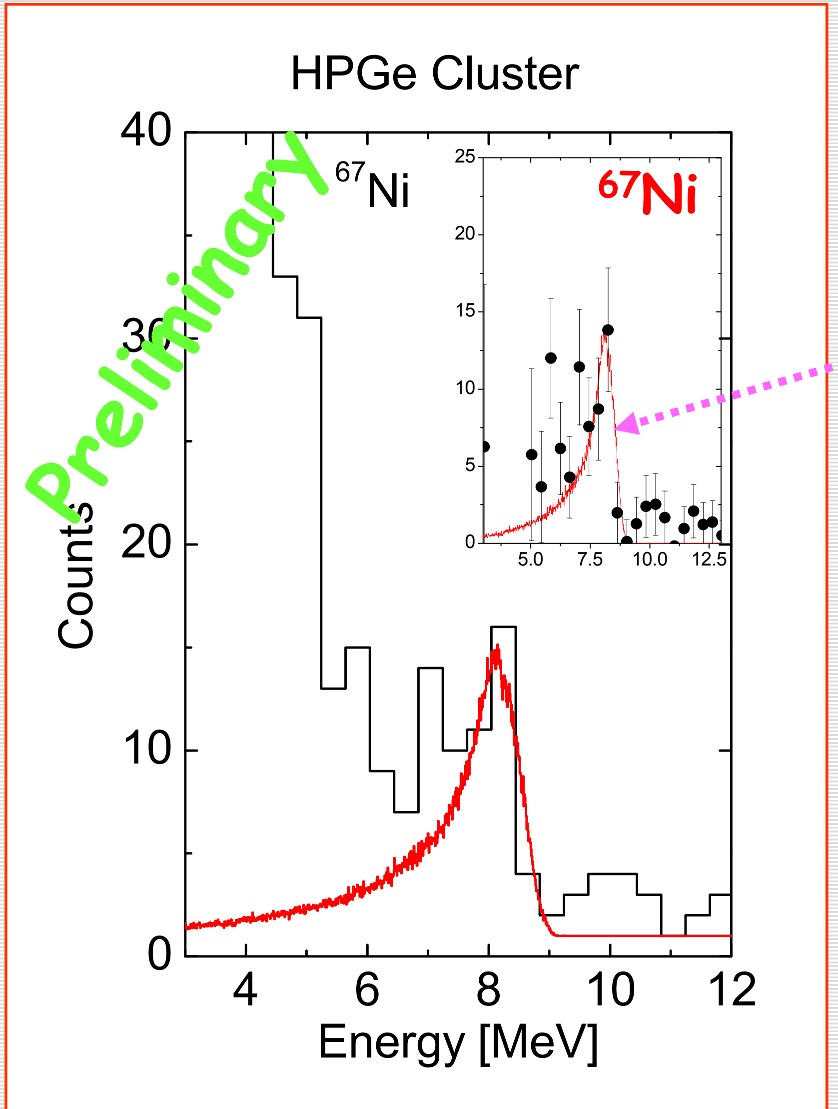


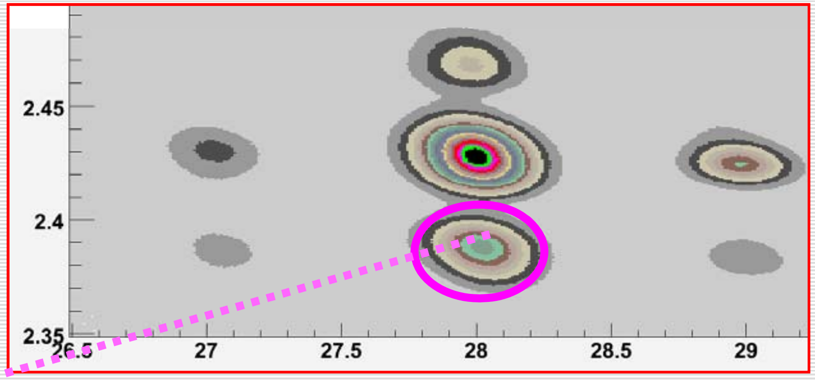

[10] *Y. Alhassid et al., Phys. Rev. Lett.* ***99****, 162504 (2007) and C.N.Gilbreth and Y.Alhassid, private communication*
[11] *S. I. Al-Quraishi et al. Phys. Rev.* ***C 63****, 065803 (2001) and S. I. Al-Quraishi et al. Phys. Rev.* ***C 67****, 015803 (2003)*
[12] *P. Demetriou, S. Goriely, Nucl. Phys.* ***A695****, 95 (2001)*
[13] *W. Dilg, W. Schantl, H. Vonach, and M. Uhl, Nucl. Phys.* ***A217****, 269 (1973)*

[10] *Shell Model Monte Carlo Method*
[11] *Extrapolation from known levels to exotic nuclei*
[12] *HF-BCS* MSk7 Skyrme *http://www-nds.ipen.br/RIPL-2/densities.html*
[13] *Back-shifted Fermi gas model*
(*)*Microscopic LD* HF-Bogolyubov BSK 14 Skyrme *http://www-astro.ulb.ac.be/Nucdata/Nld_comb_ph/z028.tab*
*[S. Goriely, S. Hilaire and A.J. Koning, Phys. Rev. C78 (2008) 064307]*

*<LD> (-1) around E*=11 MeV:*
*Al-Quraishi-ca.50*
*BRUSLIB*-ca.180*
*Alhassid-ca.500*
*Empire.-ca.600*
*Cascade-ca.2000*

# Coulomb excitation of $^{67}$Ni (600 MeV A) . . .



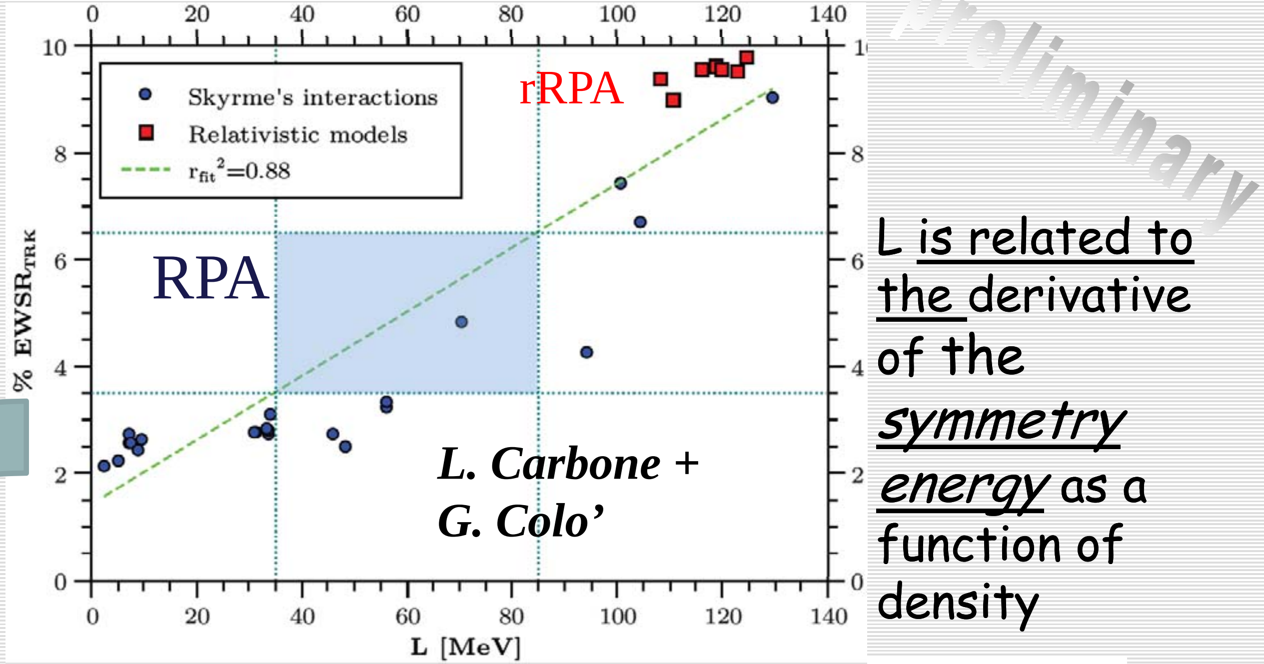

**Predictions are available only for $^{68}$Ni**

for $^{67}$Ni we see a strength at an energy 2 MeV lower.
As a simple rule the energy of the PDR should be correlated to the neutron binding energy

$E_b$ ($^{68}$Ni) ~ 7.8 MeV
$E_b$ ($^{67}$Ni) ~ 5.8 MeV

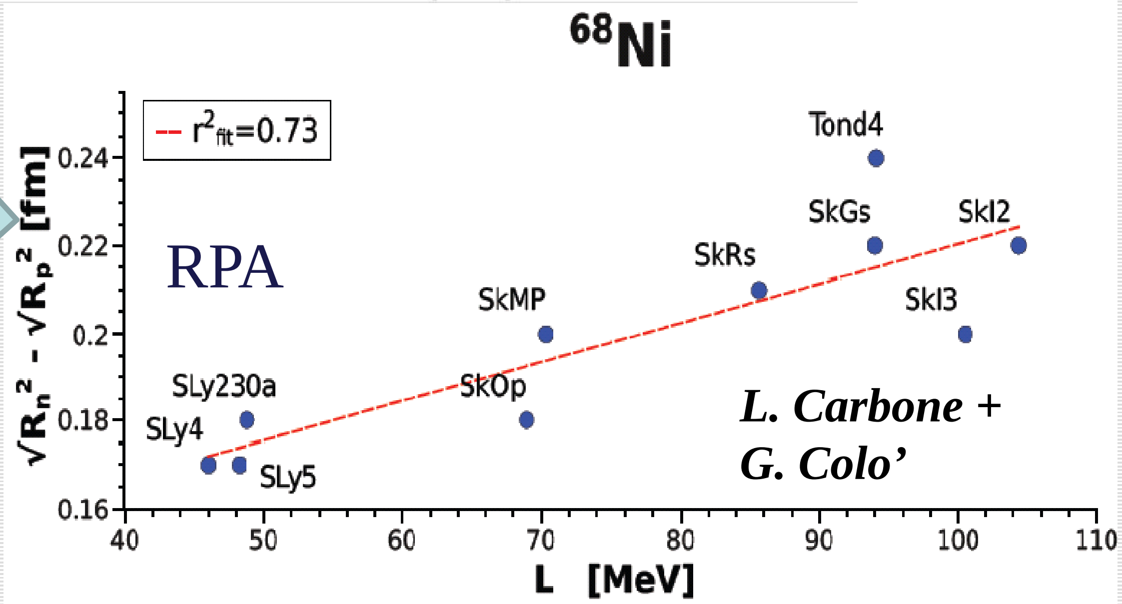
## ….. In progress … to extract information on the skin radius

**In this Framework:**
**Relation** between
**Dipole strength** and **L**
will be **also** computed

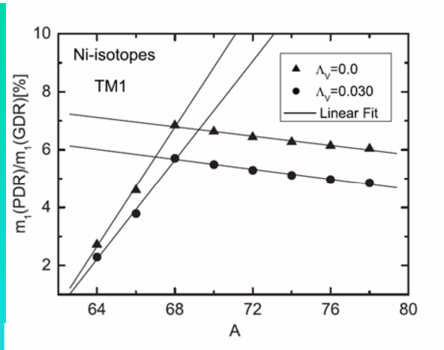



L is related to the derivative of the *symmetry energy* as a function of density

From measured strength get the neutron radius

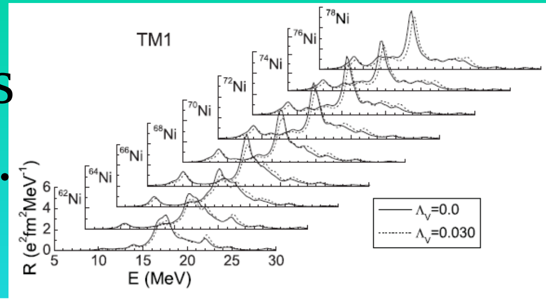


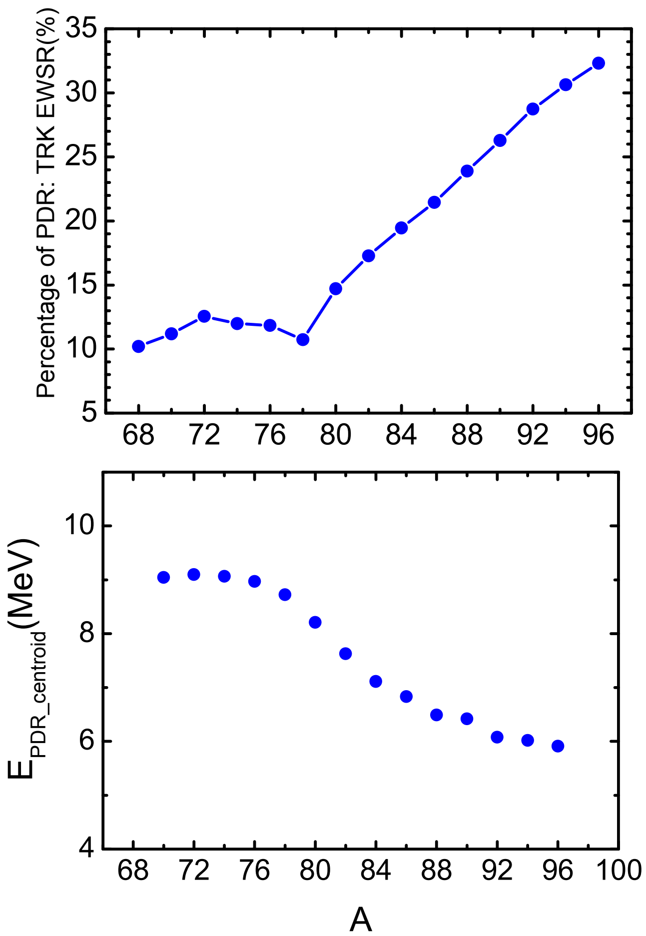

→ Compare with other methods :
e. g. analysis of HI data (isospin diffusion).

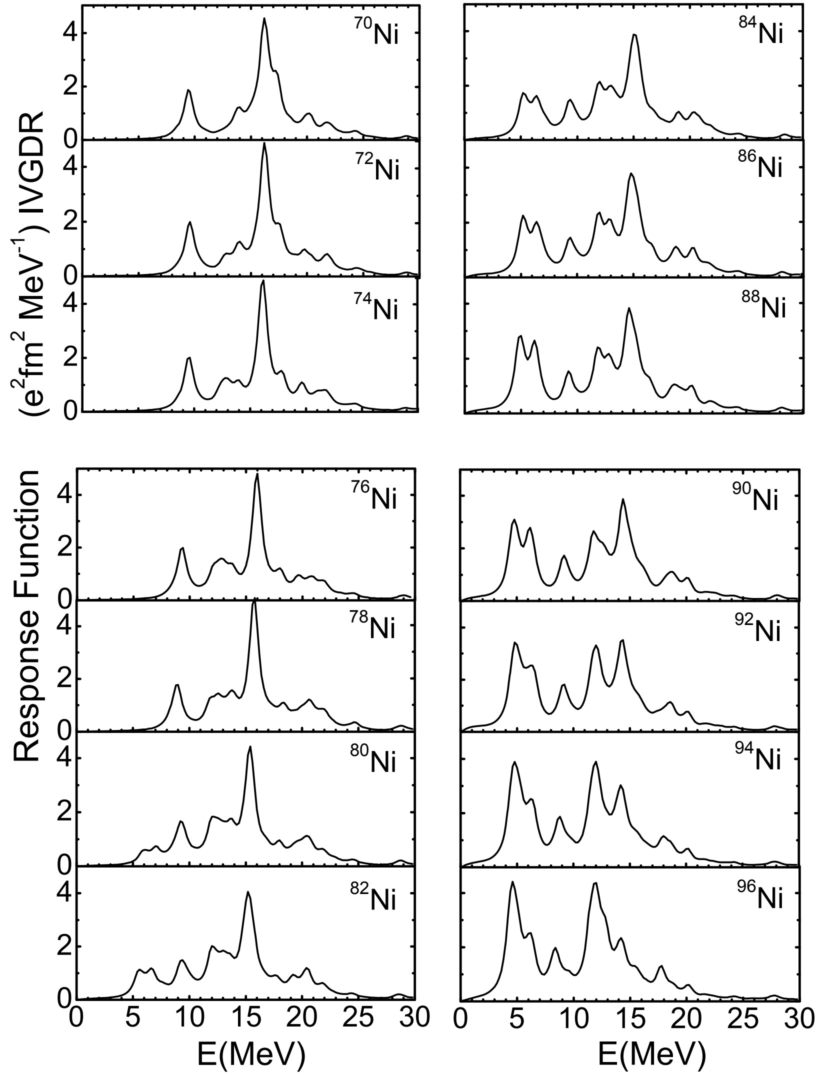



# Systematic studies are starting (1) ….

PHYSICAL REVIEW C 75, 054320 (2007)
Jun Liang, Li-Gang Cao and Zhong-Yu Ma
*And G. Colo' + L. Carbone as seen before*

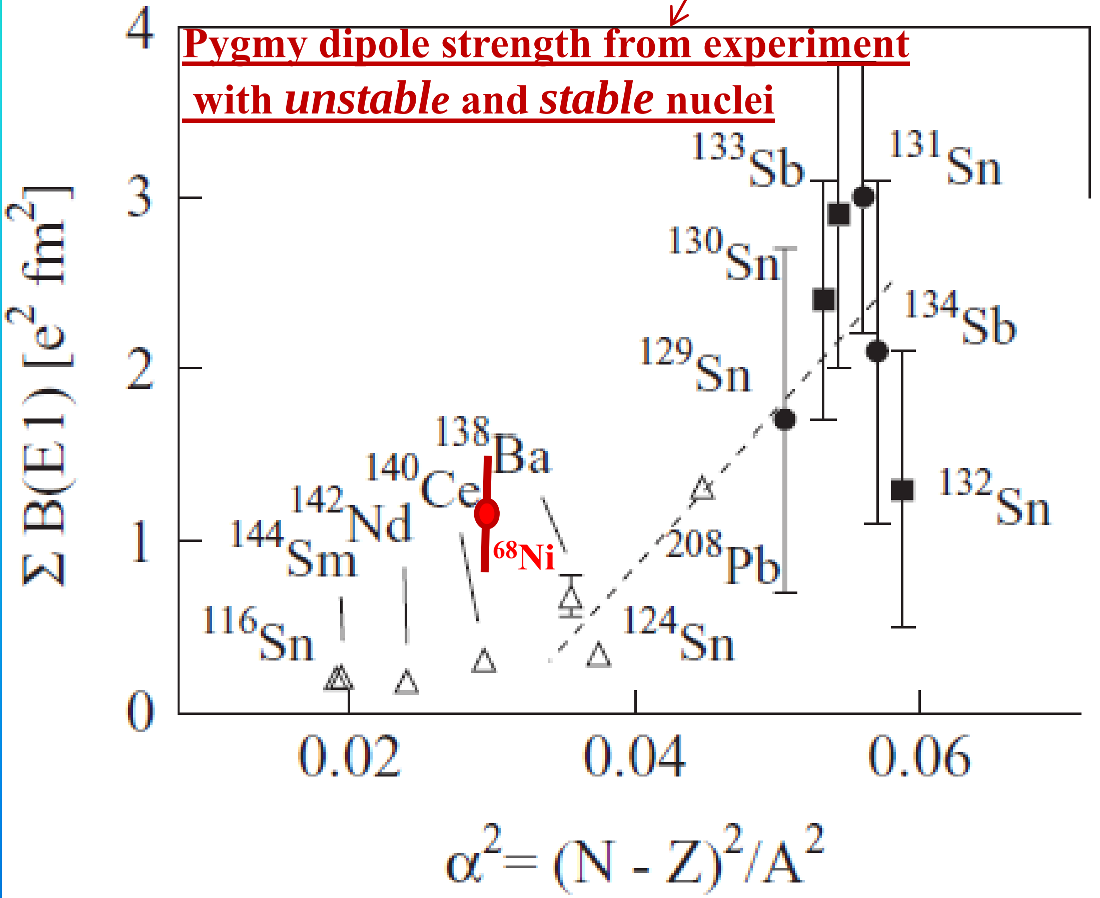



Cao, Ma, Modern Phys. Lett. A19(2004)2845

# Systematic studies are starting (2) ….




A. Klimkiewicz et al. PHYSICAL REVIEW C **76, 051603 ®(2007)**

**Pygmy-Strength is related to skin and could constrain the density dependence of S(ρ)**

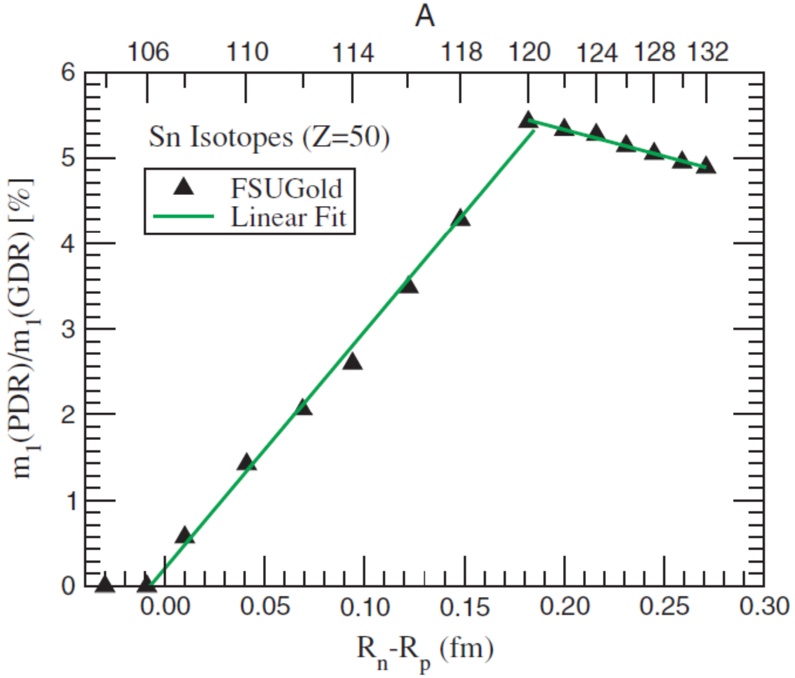


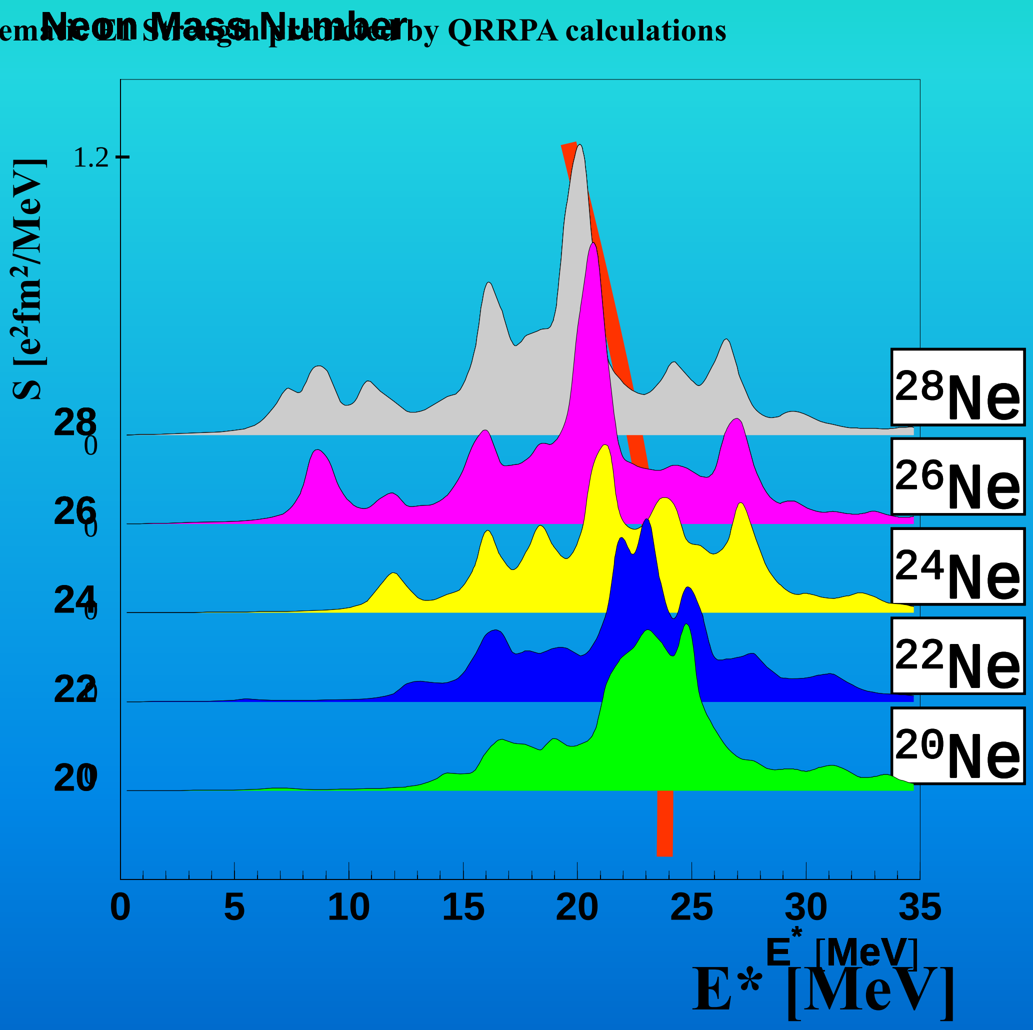

FIG. 4. (Color online) Fraction of the energy-weighted sum rule contained in the low-energy region (5−10 MeV) relative to that in the high-energy region (10−25 MeV) as a function of the neutron skin of the various Sn-isotopes.

J. Piekarewicz PHYSICAL REVIEW C **73, 044325 (2006)**

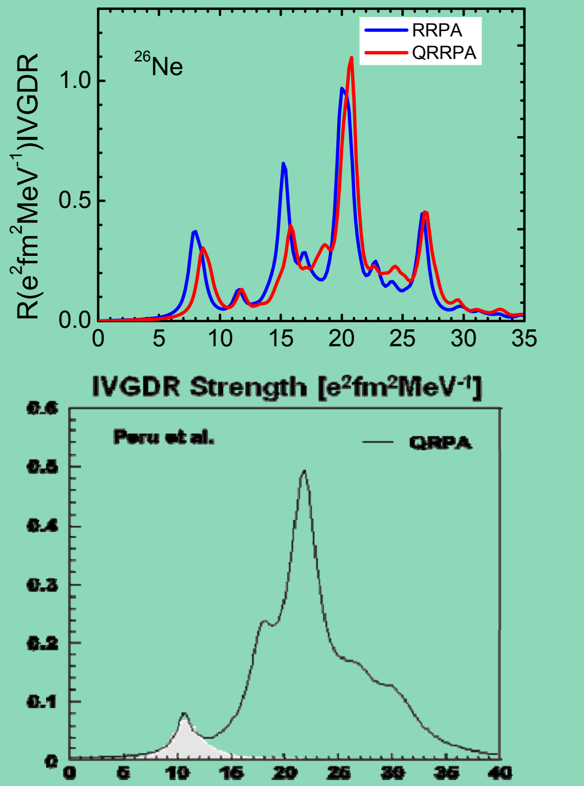
# *Planed* next *Measurements*

## Predictions in $^{XX}Ne$

Systematic E1 Strength predicted by QRRPA calculations




Cao L.-G. and Ma Z.-Y. Phys. Rev. C 71, 034305 (2005)



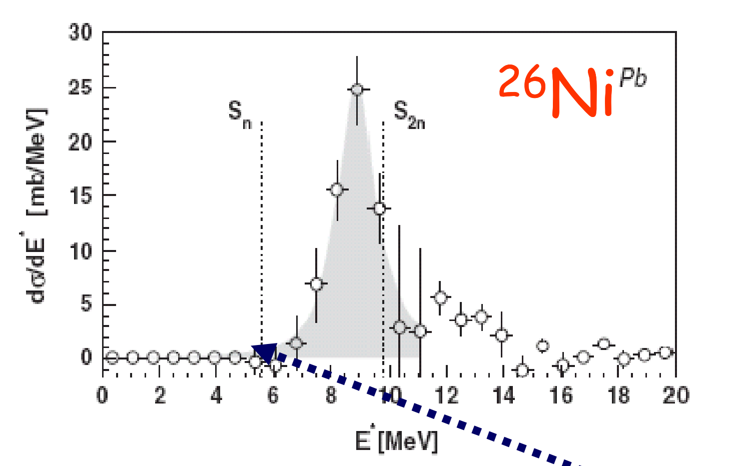

$S_{pygmy}/S_{TRK} \sim 5\%$

**Figure 2: Dipole strength distributions calculations for $^{26}Ne$ in function of the gamma ray energy. In the left panel predictions by QRRPA calculations [17] are shown, in the right panel the results of HFB+QRPA calculations are shown [18]. The two different calculated strength distributions for $^{26}Ne$ in function of the gamma ray energy gives for the PDR state, 4,5% (of TRK sum rule) at 8 MeV and 1,5% at 10.5 MeV respectively.**

PRL 101, 212503 (2008) PHYSICAL REVIEW LETTERS week ending 21 NOVEMBER 2008

# Decay Pattern of Pygmy States Observed in Neutron-Rich $^{26}$Ne

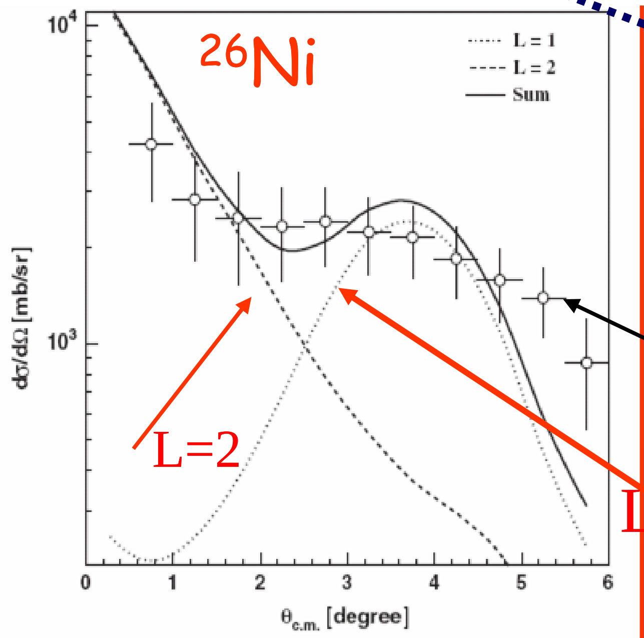
J. Gibelin et al.




RIKEN experiment at 58 MeV/u

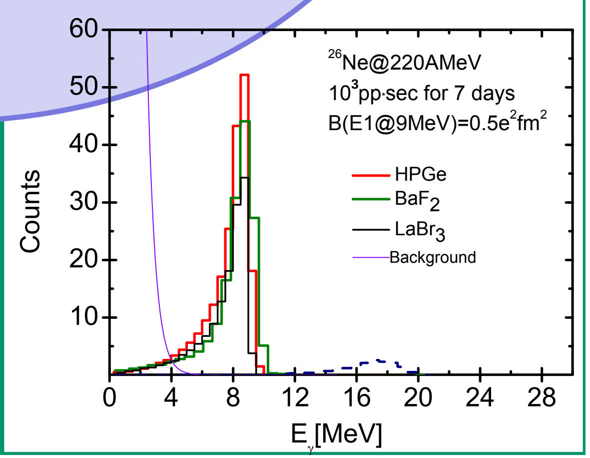
pygmy with 4.9 (p/m 1.6) % EWSR

Planned at GSI:
high energy and
virtual photon
scattering
technique ! :
search strength ALSO
below $S_n$




Coulomb break-up

Neutron detection and
gamma rays
of the residual $^{25}$Ne



## *Planed* **next** *Measurements*

Pygmy in light nuclei :

- e.g. Ne neutron rich nuclei (measured at RIKEN with virtual photon break-up)
- improve the count rate of the set up because it has a smaller cross section than $^{68}$Ni

Pygmy in neutron rich nuclei in mass 100- 130

- Improve the energy resolution of the particle detector after target

- We **need** level density calculations (or measurements) for E around the threshold for proposals, and analysis

- Even-odd nuclei?

# CONCLUSION

- Measurement of high energy $\gamma$-rays from Coulex of $^{68}$Ni at 600 MeV/u.
  - Strength at 11 MeV has been observed in all three kind of detectors
  - We found an extra strenght at 11 MeV with around 5% (+/- 1.5%) of the EWSR. The error is related by the assumption of the Level density.
  - The theory (RMF and RRPA calculations) predicts 4-8%.
  - The results opens new perspectives for other experiments and are very promising for Future measurements especially with **high resolution**

# Measurements with *stable* beams

Laboratori Nazionali di Legnaro

1. Restoration of the Isopin mixing in N=Z $^{80}Zr$ at high temperature studied with the measurement of the $\gamma$-decay of GDR

- Method and ("Theoretical") background
- Measurement
- Outlook

G.AR.F.I.E.L.D.
HECTOR

INFN Istituto Nazionale di Fisica Nucleare

# Introduction (very brief and fast)

**Isospin (** $I_z = \frac{1}{2}(N-Z)$ **)** is a **good** quantum number for the **strong interaction** and therefore the Hamiltonian is symmetric against exchange of n and p

➔ **Coulomb interaction** is isospin violating/**breaking** → **MIXING (Isospin is not conserved)**

• in the **g.s** and in low lying states: isospin mixing α, around <**5%**

## OPEN QUESTIONS

• **how does mixing change (with Temperature→E*) for Z and A ??**

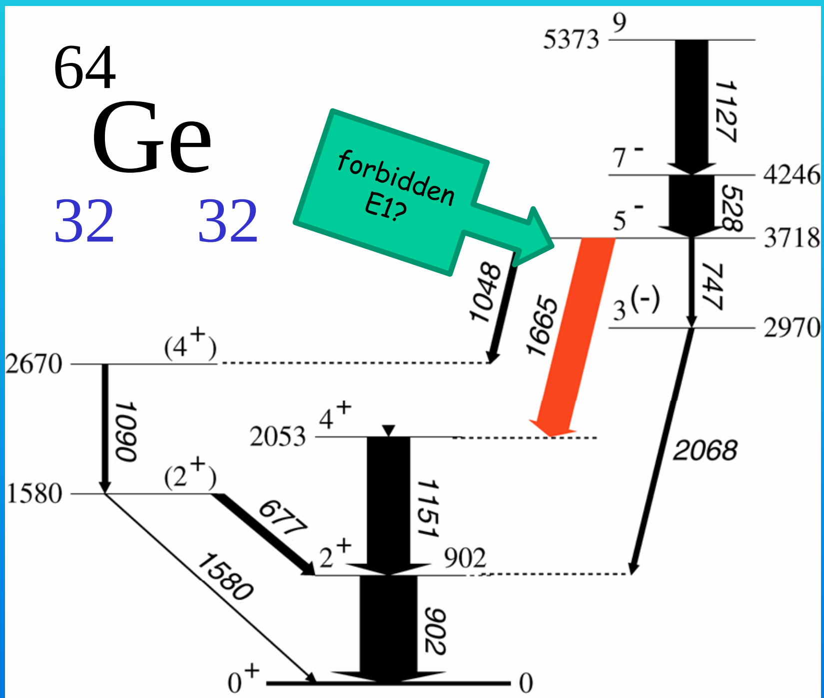
•**How to measure this in un/stable N=Z nuclei ??**

# *Isospin mixing* and forbidden E1 decay in N=Z

N=Z Nuclei :

The electric dipole transitions (without mixing) in long- wavelength limit are strictly (ISOSPIN ) forbidden in states with the same isospin

Temperature= 0

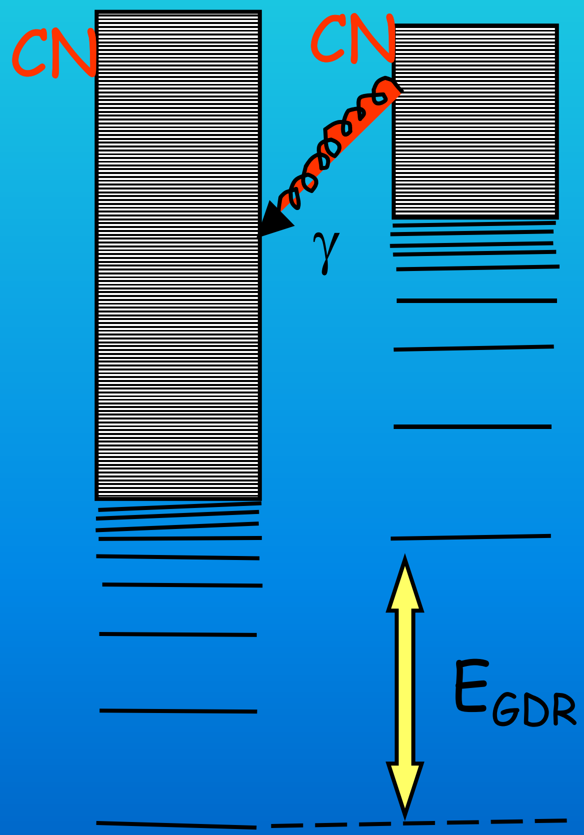



E. Farnea et al. PLB 551,(2003)55

$\alpha^2$=2.50(+1.0-0.7)%

Measure rates of isospin forbidden transitions
To determine Coulomb-induced isospin mixing !

Temperature > 0

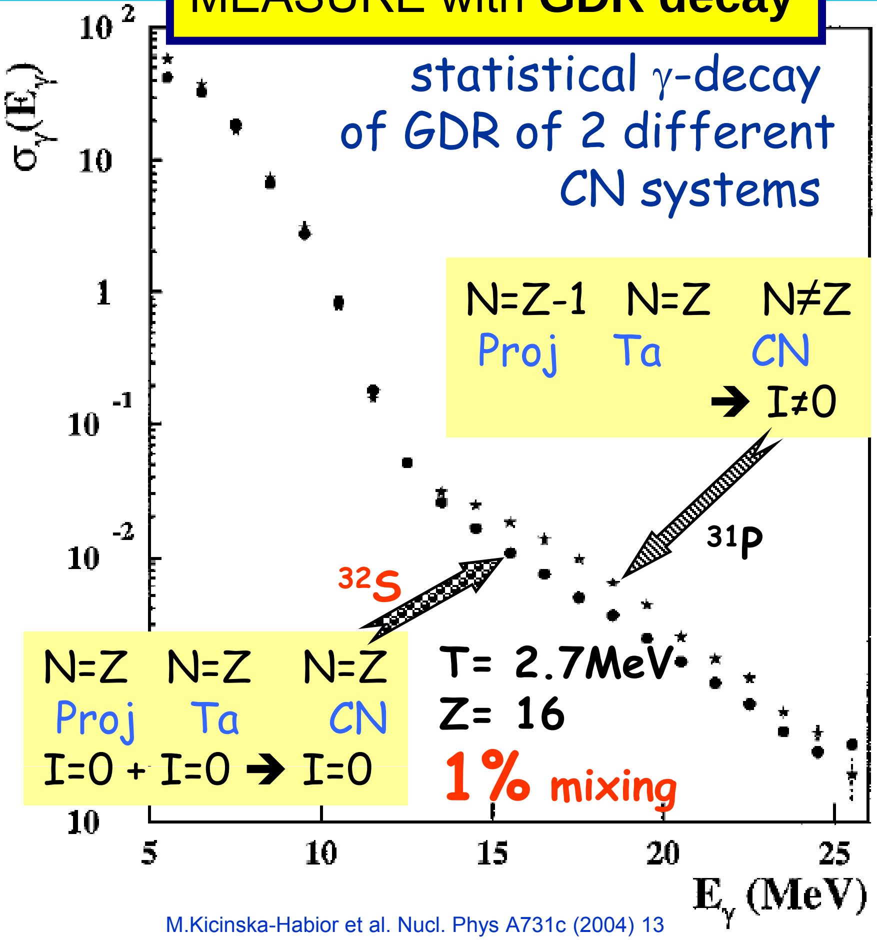



Selection rule:
**E1 decays correspond to *change* of isospin**

# Temperature > 0

- how does mixing <u>change</u> (with Temperature) for Z and A ??
- How to <u>measure</u> this in hot un/stable nuclei ??

**MEASURE with GDR decay**




M.Kicinska-Habior et al. Nucl. Phys A731c (2004) 13

**E1 (isovector GDR)** transitions (ΔI=1)

$I_{inital}$= 0 ➔ $I_{final}$= 0 are **forbidden**

$I_{inital}$= 0 ➔ $I_{final}$ = 1 are allowed

***<u>In the N=Z CN we have ρ(I=0) > ρ(I=1)</u>***

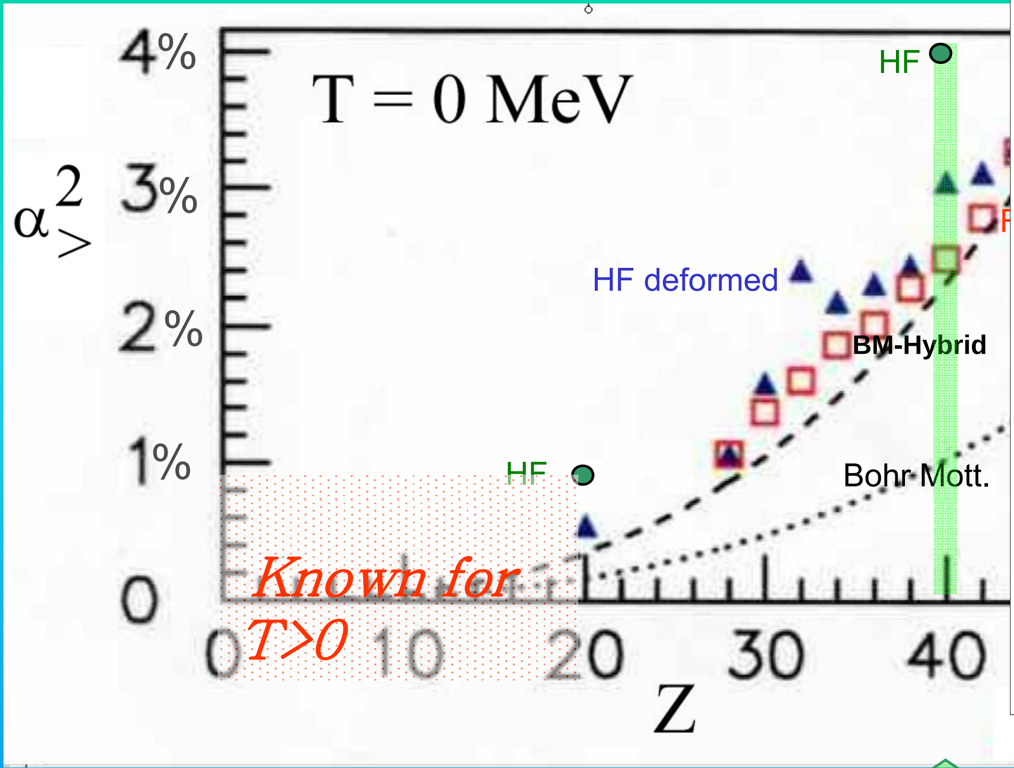
**γ yield from CN is suppressed**

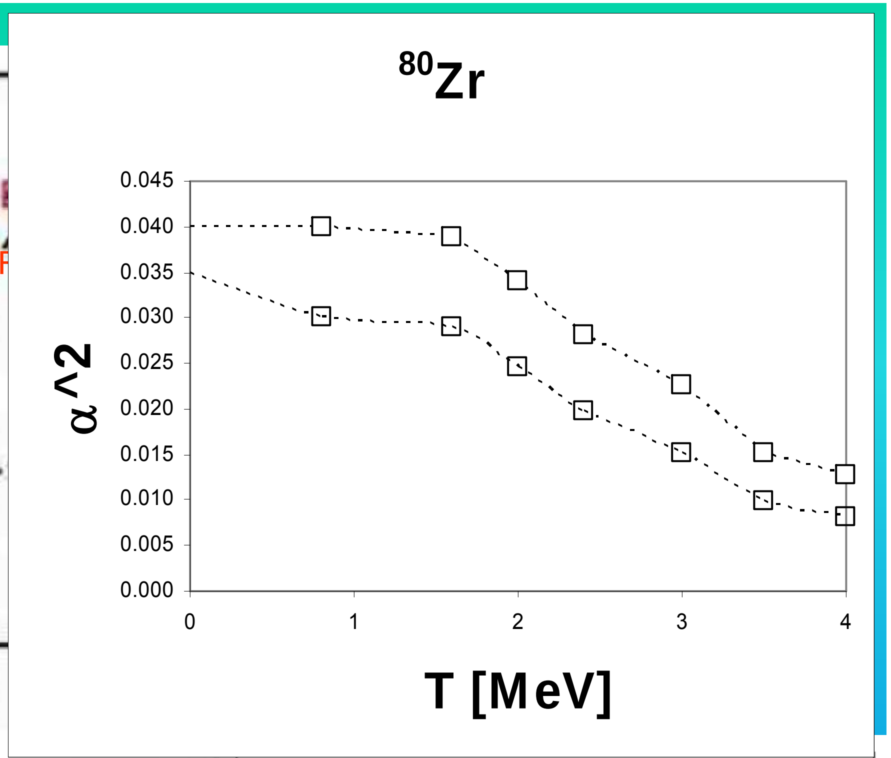
when $I_{inital\_CN}$ = 0

**Comparison**

of yield of GDR in a **N= Z** CN
to the one of **N≠ Z** CN

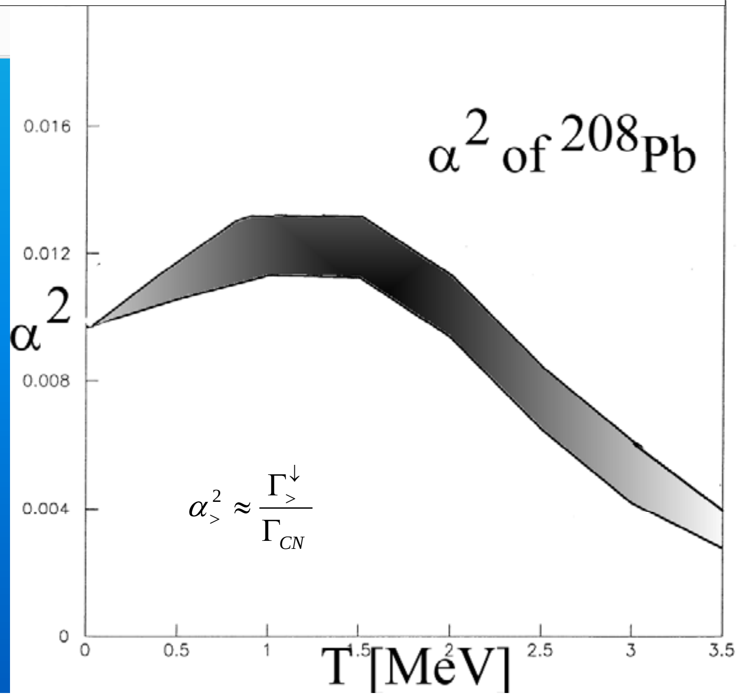
The <u>observed **suppression**</u> between these two yields depends on the degree of **<u>isospin mixing</u>** in the CN system




G. Colo, M.A. Nagarajan, P. Van Isacker, A. Vitturi PRC 52(1995)1175 and ref. therein

Z-dependence

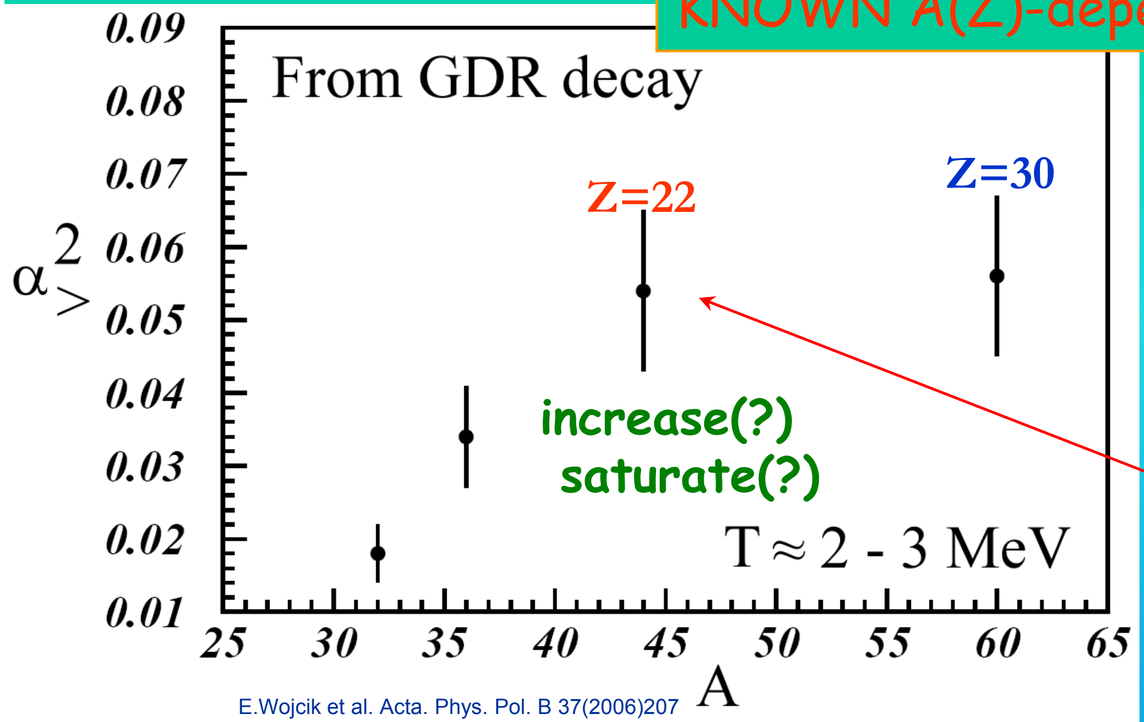



**The Isospin Mixing $\alpha_>$ Probability is predicted to decrease with temperature for T>1 MeV**

$$|g.s.> = \sqrt{1-\alpha_>^2}\,|I = I_0> + \alpha_>\,|I = I_0 + 1>$$

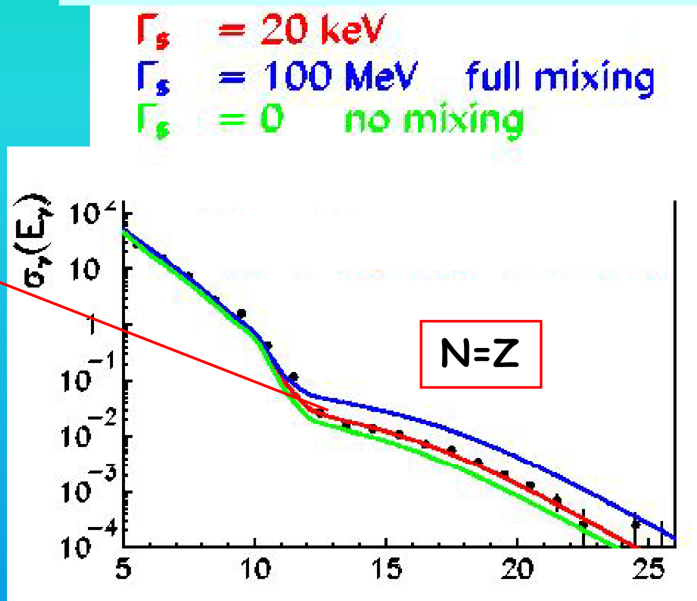
H. Sagawa, P.F. Bortignon, G. Colo Phys. Lett B444(1998)1

# KNOWN A(Z)-dependence




E.Wojcik et al. Acta. Phys. Pol. B 37(2006)207

Statistical model to determine isospin mixture



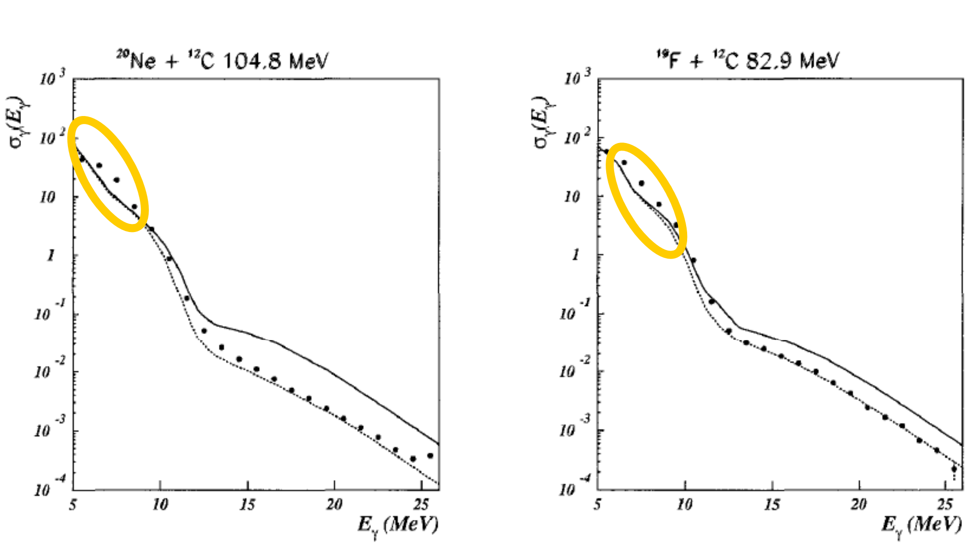

• up to mass ≈ 40 the isospin mixing $\alpha^2_>$ increases similarly to its behaviour at T=0 MeV,

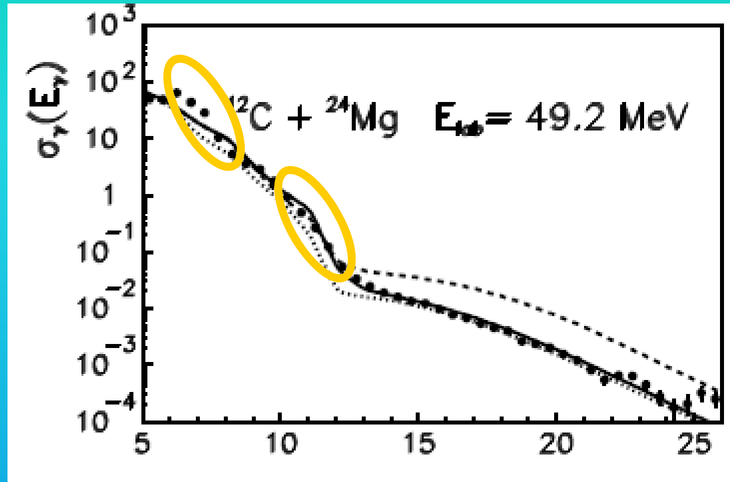
• while at A = 60 it does not increase **as one would expect**?

• Measurement at **A=80** will help to clarify !

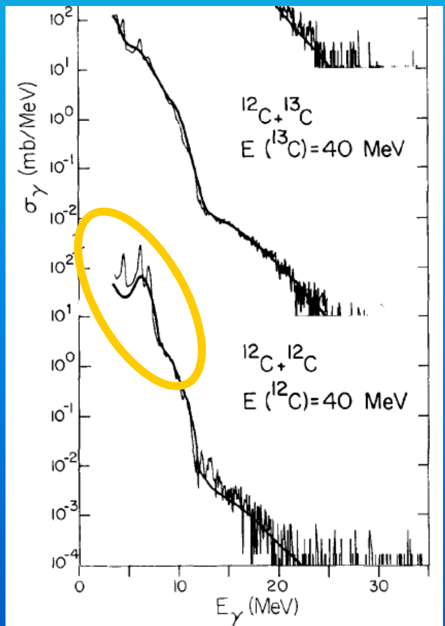
It has to be noted that all available literature data are only INCLUSIVE measurements for low mixing parameters !

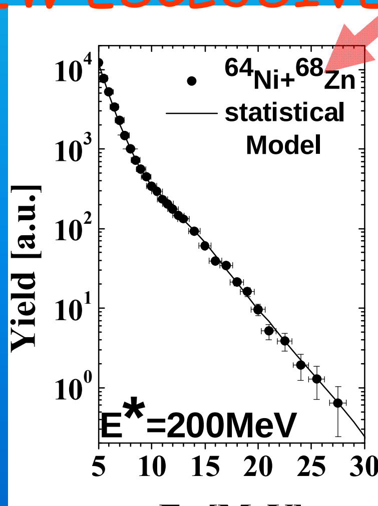
M. Kicińska-Habior et al. / Nuclear Physics A731 (2004) 138–145 141



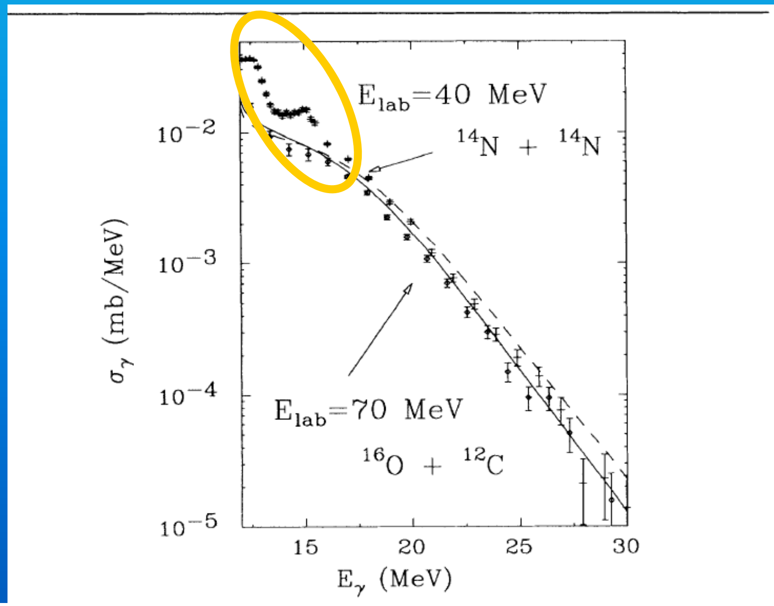




NEW ESCLUSIVE MEASURMENTS ARE NEEDED !



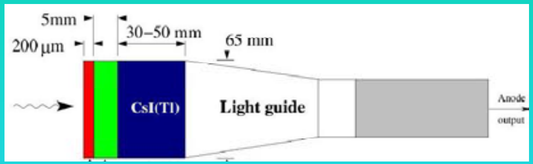

Example: Exclusive GARFIELD+HECTOR Gamma ray spectra

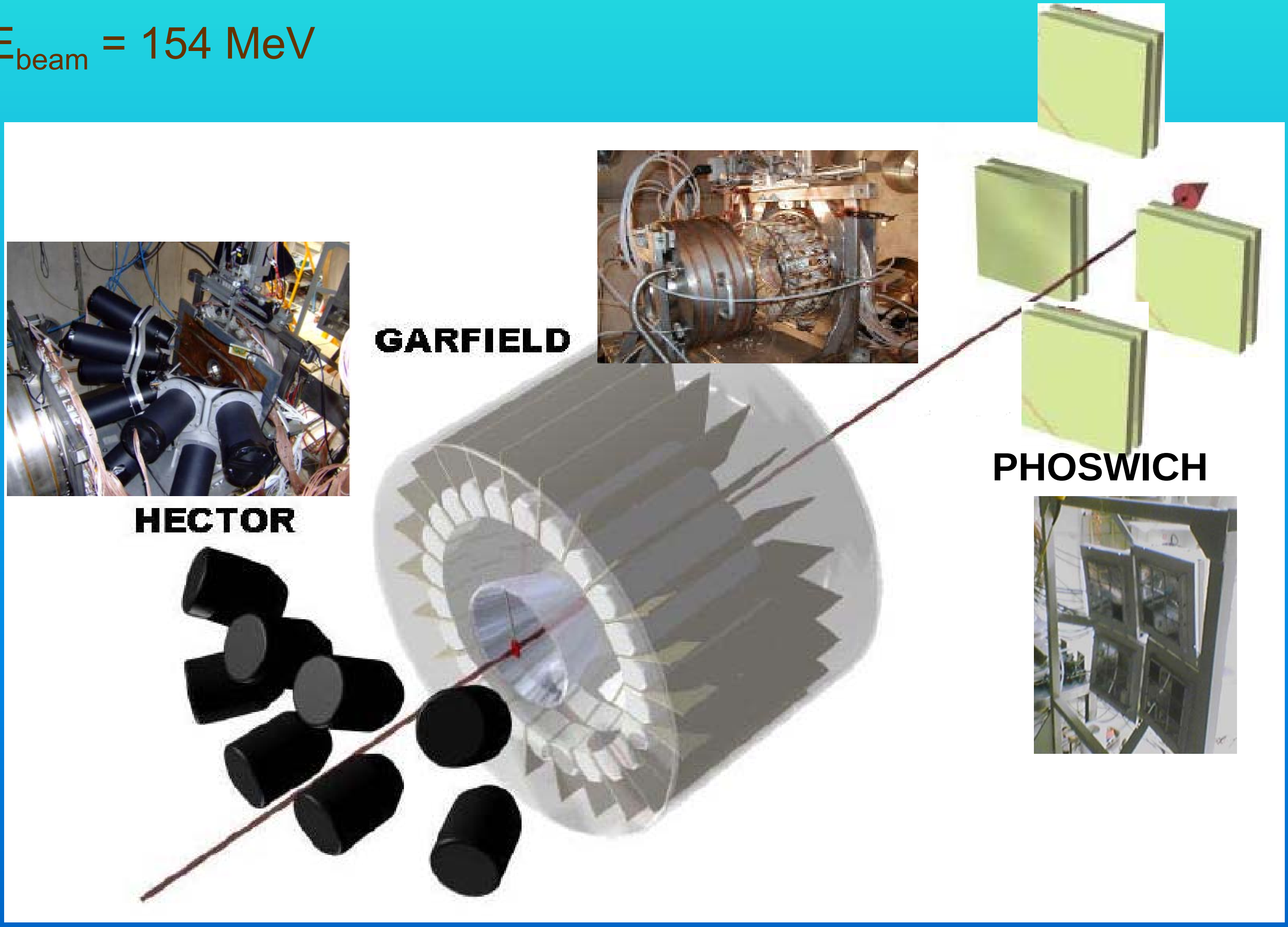


# GARFIELD+HECTOR @ Laboratori Nazionali di Legnaro

## Two reactions – Same compound

$^{40}Ca + ^{40}Ca$ with $E_{beam}$ = 200 MeV
→ $^{80}Zr$ with I=0
$^{37}Cl + ^{44}Ca$ with $E_{beam}$ = 154 MeV
→ $^{81}Rb$ with I≠0

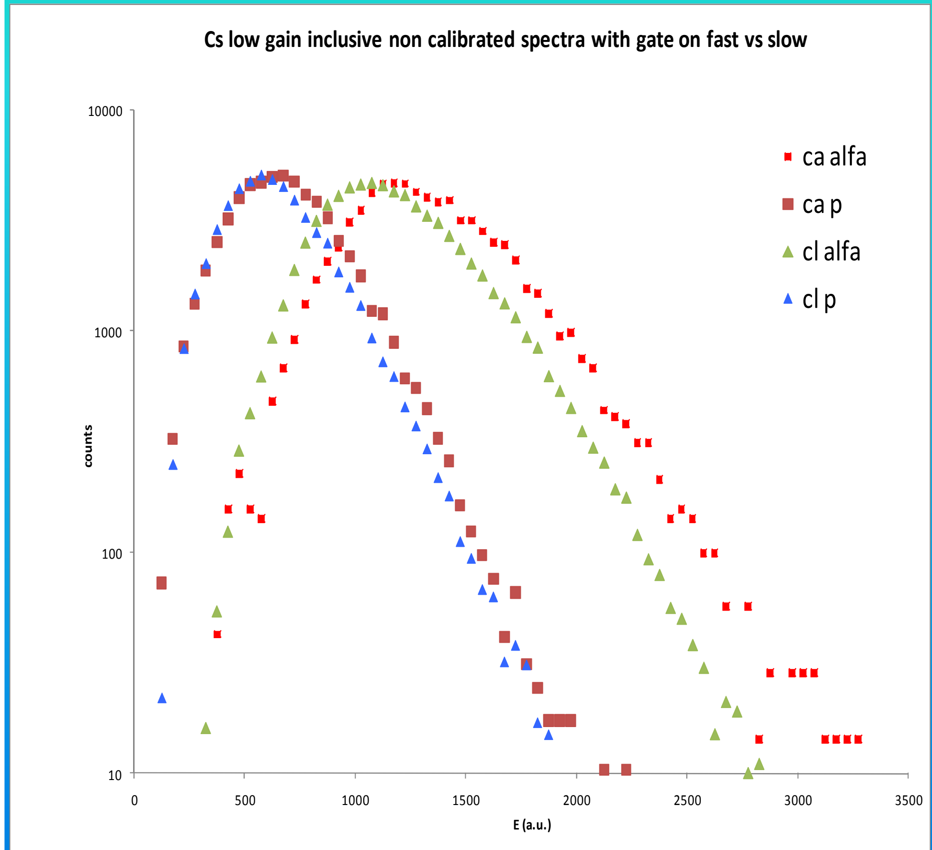


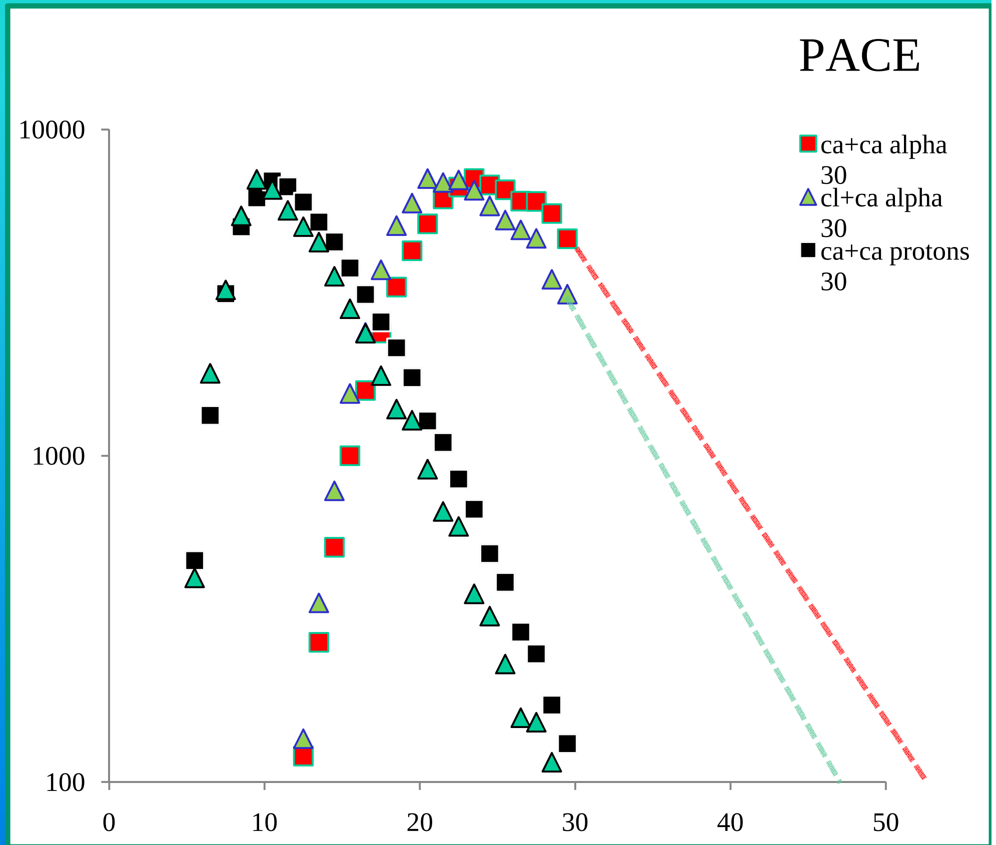



Preliminary Results

# Measurement

# Stat. Model.

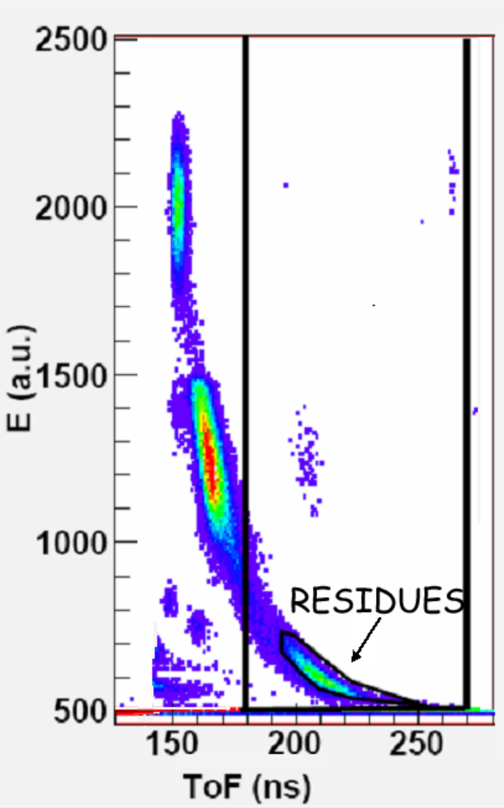



→Thermalized emission from "identical" both Compound systems at same E* and T

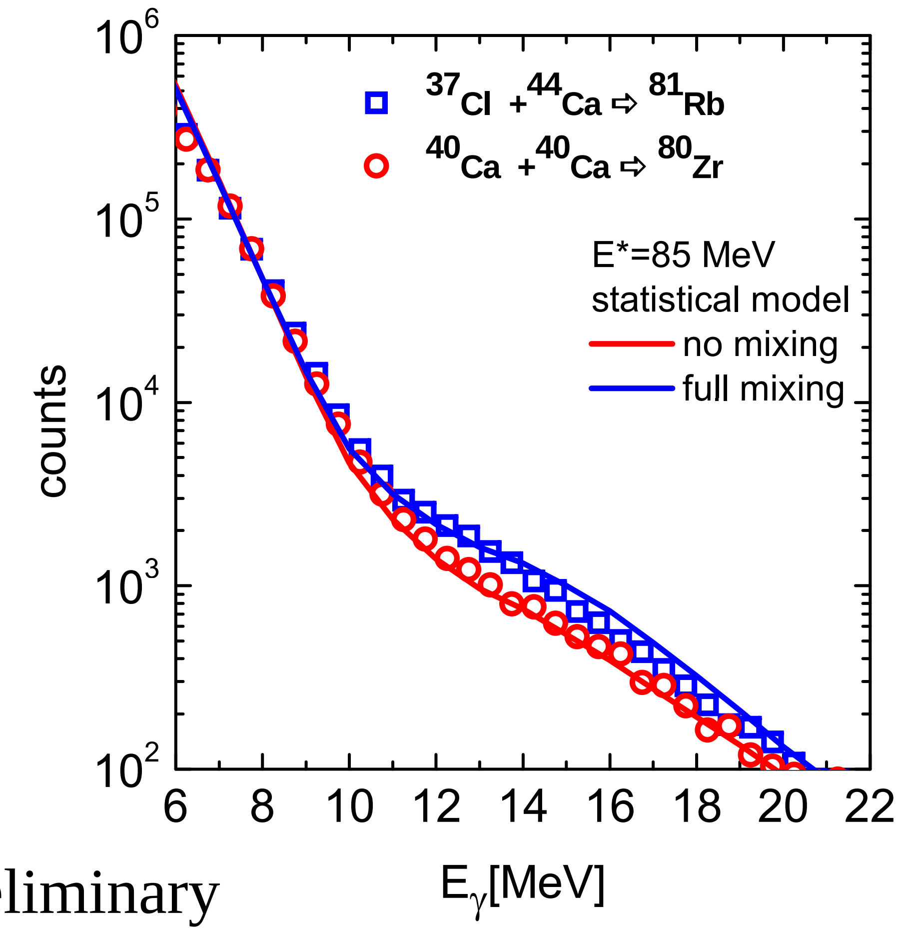
# Preliminary analysis:

PHOSWICH energy (1st layer) vs Tof




HECTOR γ spectra:

**Statistical Model** with **full** and **no** isospin mixing




**Determine $\alpha^2$** ← Preliminary

## Isopin mixing in N=Z $^{80}$Zr at high temperature

- It was possible to measure symmetric $^{40}$Ca+$^{40}$Ca=$^{80}$Zr reaction at high temperature, not accessible with other methods
- Statistical model simulations together with experimental data and teoretical analysis will give **insight** into restoration of Isospin mixing at high temperature
- **FUTURE:**

**Beams to use:** $^{44}$Ti, $^{56}$Ni, $^{72}$Kr …?

**Nuclei to study:** $^{84}$Mo, $^{96}$Cd, $^{112}$Ba,…

**Method:** excite GDR in N = Z nucleus by

complete fusion reaction

measure gamma-ray (and light particle) spectra

analyze GDR statistical gamma-decay

| Proj. | Target | CN |
|---|---|---|
| $^{44}$Ti | $^{24}$Mg | $^{68}$Se |
| $^{56}$Ni | $^{12}$C | $^{68}$Se |
| $^{56}$Ni | $^{24}$Mg | $^{80}$Zr |
| $^{44}$Ti | $^{40}$Ca | $^{84}$Mo |
| $^{56}$Ni | $^{28}$Si | $^{84}$Mo |
| $^{72}$Kr | $^{12}$C | $^{84}$Mo |
| $^{56}$Ni | $^{40}$Ca | $^{96}$Cd |
| $^{72}$Kr | $^{24}$Mg | $^{96}$Cd |
| $^{72}$Kr | $^{28}$Si | $^{100}$Sn |

N=Z

G.AR.F.I.E.L.D.
HECTOR

# Garfield + Hector collaboration

**O.Wieland, A.Bracco, F.Camera, A.Corsi, S.Brambilla, G.Benzoni, F.CL.Crespi, S.Leoni, B.Million, D.Montanari, A.Moroni, N.Blasi,**
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*INFN, Sezione di Bologna, Firenze, Italy*

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…

Istituto Nazionale di Fisica Nucleare

## RISING PYGMY Collaboration


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**R. Lozeva[c], N. Saito[c], T. Saito[c], H. Schaffner[c]**

**H.J. Wollersheim[c], J. Jolie[d], P. Reiter[d], N. Warr[d]**

**G. de Angelis[e], A. Gadea[e], D. Napoli[e], S. Lenzi[f] , S. Lunardi[f]**

**D. Balabanski[g], G. Lo Bianco[g], C. Petrache[g], A. Saltarelli[g]**

**M. Castoldi[h], A. Zucchiatti[h], J. Walker[i], A. Bürger[j]**

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